Maria João Guimarães Fonseca

EFFECTIVENESS OF INNOVATIVE RESOURCES TO PROMOTE BIOTECHNOLOGY EDUCATION AT ELEMENTARY SCHOOL AND HIGH SCHOOL

Faculdade de Ciências, Universidade do Porto

2012

U. PORTO
FACULDADE DE CIÊNCIAS
UNIVERSIDADE DO PORTO

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Tese submetida à Faculdade de Ciências, Universidade do Porto para a obtenção do grau de Doutor em Ensino e Divulgação das Ciências.

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2012

The work presented in this thesis was carried out at Faculdade de Ciências, Universidade do Porto, IBMC - Instituto de Biologia Molecular e Celular, Universidade do Porto, and CIBIO - Centro de Investigação em Biodiversidade e Recursos Genéticos, Universidade do Porto, and financially supported by the Fundação para a Ciência e a Tecnologia (FCT) fellowship SFRH/BD/37389/2007.

À minha Mãe, ao meu Pai,

e às minhas Esmeraldas.

À Sara também.

‘Se podes olhar vê. Se podes ver repara’

José Saramago

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Acknowledgments

During the development of this project I was lucky enough to be able to count on the support of a group of people with whom I must humbly share the merit of having accomplished the work depicted in this thesis. I would like to express my gratitude to everyone who directly or indirectly contributed to the completion of my PhD project.

Ao Professor Fernando, por tudo. Por ser meu Orientador e tudo o que isso implica. Por ter aceite um desafio que (mais do que) muitos recusariam sem pestanejar. Por estar sempre presente e atento, e pela liberdade criativa que sempre me deu. Por ser justo e se importar. E pela inesgotante paciência para todos os meus barrocos e rococós. E, por que ambos sabemos que poderia facilmente (e justificadamente!) esgotar o espaço dos agradecimentos só com o do Professor, fico por aqui!

À Professora Leonor, pela disponibilidade com que aceitou participar neste projecto e pela ajuda preciosa que deu ao longo de todo o trabalho. Por me pôr em contacto com pessoas e eventos de extrema importância.

Ao Professor Patrício, também pela disponibilidade e paciência com que sempre respondeu às minhas infinitas questões sobre testes, testes e mais testes. E pelo óptimo sentido critico.

Ao Professor Calafate, pelas palavras sempre inspiradoras e pela amizade. Pela forma original e inovadora com que olha para… tudo! Pelos desafios que lança, sempre e por me mostrar que é possível sempre mais!

À Professora Arminda Torres, porque se tivesse que recuar no tempo e apontar a causa da minha motivação (intrínseca) para a educação e comunicação de ciência, seria a Professora que iríamos encontrar. Obrigada por ter sido minha Professora e por tudo o que me mostrou.

À Catarina, por ser exactamente como é e pelo apoio inestimável que deu desde o início do projecto. Por, sempre humilde, ser uma pessoa, uma amiga, excepcional. Pelo interesse e ajuda constantes. Pelo rigor extremo que imprime na execução de cada tarefa a que se propõe e pela inteligência, pertinência e cuidado de cada comentário que tece.

Ao Júlio, e à Rita, pela colaboração e pelos contactos que mediaram. À Professora Elisa, à Professora Rosa, à Professora Sónia e ao Professor Rui, pelo seu tempo e disponibilidade. Por toda a ajuda e feedback, sem os quais este trabalho não teria sido possível. Aos Professores Maria dos Anjos, Lucinda, Rosa, Edite, Paula, Alexandra, Antonieta, Carla, André, Carlos, Maria Manuel, Maria João, Teresa, Graça, Renato, Filipa, António, Rosa, Fátima, Maria, Isabel, Luís, Cátia, Ana, Carminda, Vera, Vasco, Bárbara, Hugo. E a tantos outros Professores, Alunos e Escolas, que aceitaram colaborar connosco nas diversas fases do projecto, constituindo-se como peças fundamentais para a consecução dos objectivos deste trabalho.

Ao Júlio e à Rita, outra vez, ao Francis, à Anna, ao Nuno, ao Professor José Pissarra, à Professora Susana, e a todos os que me incentivaram a participar em projectos paralelos que em muito contribuíram para aprofundar algumas questões que indirectamente foram surgindo, bem como para desenvolver competências que se revelaram úteis para o próprio projecto.

À Carla, porque apesar de achar que não, tudo o que se passou naquele ano lectivo foi não só suficiente, como mesmo muito útil. Aliás, foi fundamental! Por me ter ensinado a trabalhar sobre pressão, tendo sempre em mente o objectivo de atingir a máxima qualidade possível. Pela amizade também!

A todos os membros (passados e presentes) do grupo de Microbiologia Celular e Aplicada e respectivos *spin-off* e do grupo MDE por me terem acolhido e terem feito com que me sentisse parte de um grupo, independentemente das inevitáveis diferenças entre as linhas de investigação que exploramos. Alexandre, Andrea, Ângela, António, Catarinas, Daniel, Daniela, Eduarda, Filipe, Helena, Joana, Kalina, Luís, Margarida, Maria Manuel, Marta, Miguel, Nuno, Paula, Paulo, Pedro, Professora Arlete, Professor Moradas, Rita, Rita, Rodrigo, Sara, Sara, Sérgio, Sílvia, Tiago, Vítor, Vítor, pelo apoio, comentários e pelo excelente ambiente de trabalho.

À Marta, pelo interesse, criatividade e ajuda com as bactérias que dão o cheiro à terra! Ao Rodrigo, por ter jeitinho a aplicar parafilm e película aderente, e por ter partilhado esse jeitinho quando foi preciso! À Joana, pelas viagens (não tão frequentes quanto deveriam) até ao metro e pelo sentido de humor mordaz. E pelas conversas sérias, no meio da palhaçada. À Sílvia, por ser genuinamente boa pessoa. Pelo carácter e sorriso maravilhosos, sempre! E por toda a ajuda e amizade. A Rob, pelos abracinhos! Por se lembrar de mim, mesmo quando não era preciso e por estar sempre lá para ajudar. Ao Pedro, pela palermice extrema (quase maior do que a minha! Quase…), por me ter aturado nos últimos tempos. A mim e às minhas irritabilidades temáticas! E por estar sempre pronto a ajudar. Ao Miguel, pela música e pelo riso. E por perceber "estrangeiro", o que às vezes se revela muito útil! Ao D., por ser meu amigo. Há coisas que surgem por acaso e (boas) pessoas que são especiais – dois clichés? Pois, foi uma surpresa constatar que estes lugares-comuns têm um fundamento real, que confirmei ao conhecer ao Daniel. É definitivamente um privilégio saber que posso contar com ele para o que for preciso.

To everyone at the ESERA summer school 2010. It was definitely a privilege to be able to share and discuss our research project and findings with such an experienced, interested and critical group of people. Thank you for your warmth and support and for making me feel part of the family! To everyone at ESERA and ERIDOB from whom I have had the pleasure of learning, especially the persons who I can now call friends.

À Patrícia, por ser uma pessoa linda. Pela amizade sincera e por acreditar em mim. Por todos os nossos planos e pela sua concretização! E por me ajudar a manter a (in)sanidade mental! À Joana, por ter perdido tempo que não tem para me ajudar. Por estar apenas a um telefonema de distância, mas sempre lá. E por "always look on the bright side of life"! Ao André, por todo o antes. E por me fazer perceber que consigo fazer mais do que o que pensava.

À minha Mãe e ao meu Pai, por tudo o que se poderia esperar e por mais ainda... Não há nem nunca haverá palavras para lhes agradecer.

Abstract

Biotechnology is an area with an increasing social impact which, in spite of its potential, raises controversy and debate. It is imperative that all citizens are able to understand and take part in the discussion that surrounds the social, ethical and economic implications of biotechnology.

Non-specialist citizens develop their knowledge about biotechnology mainly from the academic education that takes place in school and from information disseminated by the media. Therefore, science education must enable students to become more knowledgeable about the scientific and methodological bases of biotechnology, to understand how biotechnology processes can be successfully applied while respecting basic ethical principles, and to critically analyse research methods and results to make informed decisions.

The concerns about the societal implications of biotechnology have spread to the educational field, leading several educational frameworks to incorporate biotechnology-related contents in science curricula, and prompting the development of numerous resources to promote students' scientific literacy. Nevertheless, the success of this investment in biotechnology education has not been fully demonstrated, given the scarcity of reliable and consistent indicators of the effectiveness of most of the activities and programs put forth. In fact, in the last two decades much research has been conducted in assaying public perceptions about biotechnology, although the number of studies focusing on students and teachers is limited. Moreover, the studies that do exist, report preoccupying results, namely that students and teachers are reluctant to address basic biotechnology concepts, often presenting misconceptions, poor knowledge and negative attitudes.

In this context, and to fill the gap in the aforementioned research, the work discussed in this thesis was carried out with the purpose of developing, implementing and assessing innovative activities aimed at improving elementary school and high school students' (14 to 18 years old) scientific literacy about biotechnology.

To define starting points for the design of laboratory activities, a thorough characterization of students' perceptions about biotechnology and teachers' beliefs about biotechnology and biotechnology education was conducted. Following a quantitative assessment approach, two closed-ended questionnaires were purposely developed, validated, and administered to 1196 elementary school students (n=498) and high school students with different curricular backgrounds (n=698), and 93 inservice biology teachers, in Portugal. Whereas previous research on students' perceptions has mainly focused on discrete elements,

such as knowledge and attitudes, in this project, a multidimensional analysis was performed by considering these constructs, as well as motivational elements. The data gathered indicate that students' perceptions and behavioural intentions are modulated by cognitive, affective and motivational factors. Most students, particularly 9th graders and non-science 12th graders, although acknowledging the importance of biotechnology and nurturing positive attitudes towards most of its applications, revealed knowledge limitations and were not intrinsically motivated to search for information about it. Students' knowledge, attitudes, interest and importance attributed to biotechnology were found to be positively correlated.

In what concerns the teachers, their beliefs about biotechnology were positive, regardless of age, teaching experience and qualifications. However, teachers overestimated practical limitations in biotechnology education, particularly concerning material and resource limitations, which they often did not feel compelled to overcome. It was also noted that currently available innovative educational resources were underexplored by these teachers.

Taken as a whole, these findings suggest that, in order to adequately address the needs of both students' and teachers' demands, it is necessary to develop activities that: i) are based on informative, relevant and up-to-date contents; ii) foster the development of high-order thinking and reflexive competencies; iii) are easy and quick to plan and to implement; and iv) require simple and inexpensive materials.

According to these criteria, a set of activities, addressing relevant public health issues, such as antibiotic resistance and the curricular topic antibiotic production, were developed, optimised, and implemented in an informal learning environment as part of Porto's Junior University (http://universidadejunior.up.pt/) (*n*=42), and in a formal high school context, as part of 12th grade students' biology classes (*n*=147, from seven biology classes and their teachers). The effectiveness of the activities was assessed using a mix-method approach based on a pre-/post design with the use of outgroups in the school context.

In both situations, the results obtained demonstrate that the participants developed an increased awareness and understanding about antibiotic resistance, and an enhanced consciousness about the importance of judicious antibiotic use. There were also significant improvements in their procedural skills. Students and teachers alike emphasised the relevance and usefulness of the activities for the promotion of learning, engagement, and motivation. The majority of them agreed that hands-on activities when contextualised with relevant topics and aligned with the curriculum, present an invaluable contribution to attain academic goals and meet personal needs.

On a more general level, the outcomes of this work demonstrate that the efficacy of practical work is mediated by an interacting network of factors, such as students' individual and situational interest, the instructional design of the activity considered, and the amount of structuring and guidance provided.

The implications of these findings extend beyond biotechnology education, by providing an insightful evidence of the educational worth of practical work that informs science education research and practice. The indicators conveyed herein emphasise the need to critically evaluate the effects of hands-on activities, and pave the way for setting up corrective teaching policies. Furthermore, and perhaps most importantly, these results highlight the need to stimulate a sense of responsibility and awareness in the students when asked to make decisions based on scientific evidence.

Resumo

A biotecnologia é uma área com um impacto social crescente que, apesar do seu potencial, suscita controvérsia e debate. Nesse sentido, é fundamental que todos os cidadãos sejam capazes de compreender e participar na discussão acerca das implicações sociais, éticas e económicas da biotecnologia. Os cidadãos não-especialistas desenvolvem o seu conhecimento acerca de biotecnologia sobretudo através da sua formação académica e da informação veiculada pelos media. Por isso, a educação em ciência deve permitir que os alunos compreendam melhor as bases científicas e metodológicas da biotecnologia e de que forma os processos biotecnológicos podem ser aplicados com sucesso respeitando princípios éticos fundamentais, e sejam capazes de analisar criticamente os métodos e resultados da investigação, para tomarem decisões informadas.

As preocupações sobre as implicações da biotecnologia estenderam-se à educação, levando várias entidades educativas a incorporar conteúdos relacionados com biotecnologia nos currículos de ciência, e estimulando o desenvolvimento de numerosos recursos para promover a literacia científica dos alunos. Contudo, o sucesso deste investimento na educação em biotecnologia ainda não foi claramente comprovado, devido à escassez de indicadores fiáveis e consistentes da eficácia da maioria das actividades e programas disponíveis. Ao longo dos anos, um intenso esforço de investigação tem sido dedicado à análise das percepções do público em relação à biotecnologia, embora o número de estudos focados em alunos e professores seja bastante limitado. Para além disso, os estudos que existem revelam dados preocupantes, nomeadamente que alunos e professores permanecem relutantes em abordar conceitos básicos de biotecnologia, exibindo frequentemente concepções alternativas, limitações de conhecimento e atitudes negativas.

Neste contexto, e para colmatar este hiato na investigação, o trabalho discutido nesta tese tem por objectivo desenvolver, implementar e avaliar actividades inovadoras destinadas a promover a literacia científica de alunos dos ensinos básico e secundário (14 a 18 anos de idade) em relação à biotecnologia.

Para permitir a definição de pontos de partida para o design de actividades laboratoriais, foi efectuada uma caracterização exaustiva das percepções dos alunos em relação à biotecnologia e das opiniões dos professores em relação à biotecnologia e à educação em biotecnologia. Com base numa metodologia quantitativa, dois questionários foram desenvolvidos, validados e aplicados numa amostra de 1196 alunos dos ensinos básico (*n*=498) e secundário com diversos perfis académicos (*n*=698) e numa amostra de 93 professores de

biologia, em Portugal. Apesar de estudos anteriores acerca das percepções dos alunos se terem focado essencialmente em elementos discretos, tais como conhecimento e atitudes, neste projecto procedeu-se a uma análise multidimensional que teve em consideração estes constructos, bem como elementos motivacionais. Os dados recolhidos indicam que as percepções e intenções de comportamento dos alunos são moduladas por factores cognitivos, afectivos e motivacionais. A maioria dos alunos, particularmente os do 9º ano e do 12º ano de cursos não científicos, ainda que reconheçam a importância da biotecnologia e revelem atitudes positivas em relação a muitas aplicações, mostraram limitações de conhecimento e não estão intrinsecamente motivados para procurarem informação sobre estes assuntos. Verificou-se ainda que o conhecimento dos alunos, as suas atitudes, o seu interesse e a importância que atribuem à biotecnologia estão correlacionados positivamente.

No que diz respeito aos professores, as suas opiniões acerca da biotecnologia foram positivas, independentemente da idade, experiência de ensino e qualificações. Contudo, os professores sobrestimaram as limitações práticas na educação da biotecnologia, especialmente em relação a limitações de materiais e recursos, as quais muitas vezes não se sentiam motivados a ultrapassar. Também se verificou que os recursos educativos inovadores disponíveis actualmente são subexplorados por estes professores.

No seu conjunto, estes dados sugerem que, para responder adequadamente às necessidades de alunos e professores, é necessário desenvolver actividades que: i) se baseiem em conteúdos informativos, relevantes e actuais; ii) promovam o desenvolvimento de capacidades de raciocínio complexo e de reflexão; iii) sejam simples e rápidas de planear e implementar; e iv) necessitem de materiais simples e poucos dispendiosos.

De acordo com estes critérios, actividades centradas em questões de saúde pública, como por exemplo a resistência a antibióticos e no tópico curricular produção de antibióticos foram desenvolvidas, optimizadas e implementadas num ambiente informal de aprendizagem, no âmbito da Universidade Júnior (http://universidadejunior.up.pt/) (*n*=42), e num contexto formal de ensino secundário, no âmbito das aulas de Biologia de 12º ano (*n*=147 alunos de sete turmas e os seus professores). A eficácia destas actividades foi avaliada através de uma abordagem que combina métodos qualitativos e quantitativos baseada num design pré/pós-teste, com utilização e grupos controlo no caso do contexto escolar.

Os resultados obtidos em ambas as situações demonstram que os participantes melhoraram a sua apreensão e compreensão do fenómeno de resistência a antibióticos e desenvolveram uma maior consciencialização acerca da importância da utilização racional de antibióticos. Houve também melhorias significativas nas suas competências procedimentais. Tanto os alunos como os professores destacaram a relevância e utilidade das actividades para a promoção da aprendizagem, envolvimento activo e motivação. A maioria concordou que as actividades práticas, quando contextualizadas em tópicos relevantes e alinhadas com o currículo, representam uma valiosa contribuição para a consecução de objectivos académicos e necessidades pessoais.

De uma forma mais geral, os resultados deste trabalho demonstram ainda que a eficácia do trabalho prático é mediada por uma rede de factores interactuantes, tais como o interesse individual e situacional dos alunos, o design educativo da actividade considerada, e o nível de estruturação e apoio disponibilizados.

As implicações destes resultados estendem-se para além da educação em biotecnologia, ao apresentarem evidências acerca do valor educativo do trabalho prático com importância para a investigação e prática da educação em ciência. Os indicadores obtidos reforçam a necessidade de avaliar criticamente os efeitos das actividades práticas, e abrem caminho à definição de medidas correctivas de ensino e, principalmente, para a estimulação de uma responsabilização dos alunos quando lhes for pedido para tomarem decisões apoiadas em fundamentos científicos.

Résumé

La biotechnologie est un domaine dont le croissant impact social soulève, en dépit de son potentiel, le débat et la controverse. Il est impératif que le public en général soit capable de comprendre et participer au débat sur les implications sociales, éthiques et économiques de la biotechnologie.

Le grand public développe sa connaissance à propos de la biotechnologie essentiellement à partir de l'éducation académique, pendant la période scolaire, et à partir de l'information diffusée par les média. Par conséquent, l'éducation en science doit permettre aux étudiants de devenir plus informés à propos des méthodes et bases scientifiques de la biotechnologie, de comprendre comment les processus de la biotechnologie peuvent être appliqués tout en respectant les principes éthiques basiques, et analyser de façon critique les méthodes de recherche et ses résultats pour prendre des décisions informées.

Les préoccupations à propos des implications sociétales de la biotechnologie se sont étendues au domaine de l'éducation, conduisant plusieurs cadres éducationnels à incorporer des sujets liés à la biotechnologie dans leurs programmes de sciences, incitant ainsi le développement de nombreuses ressources pour promouvoir les connaissances scientifiques des étudiants. Cependant, le succès de cet investissement dans l'éducation de la biotechnologie n'a pas été complètement démontré, étant donné le manque d'indicateurs fiables et consistants de l'efficacité de la plupart des activités et programmes mis en avant. En effet, dans les deux dernières décennies beaucoup de recherches ont été conduites faisant l'évaluation des perceptions publiques à propos de la biotechnologie, bien que le nombre d'études centrés sur les étudiants et professeurs soient limité. De plus, les études qui existent démontrent des donnés inquiétantes, notamment que les étudiants et professeurs sont peu disposés à aborder les concepts basiques de la biotechnologie, présentant souvent des idées fausses, piètres connaissances et une attitude négative.

Dans ce contexte, pour combler cette lacune dans les recherches supra-mentionnées, le travail discuté dans cette thèse a pour but de développer, exécuter et évaluer des activités innovatrices ayant pour objectif l'amélioration des connaissances scientifiques des élèves de l'école secondaire (14 à 18 ans) à propos de la biotechnologie.

En vue de définir des points de départ pour la création d'activités de laboratoire, une caractérisation minutieuse à été conduite sur les perceptions qu'on les étudiants de la biotechnologie, ainsi que les opinions des professeurs à propos de la biotechnologie et de l'éducation de la biotechnologie. Suivant une approche quantitative, deux questionnaires à réponse fermé ont été spécialement développés, validés, et donnés à 1196 élèves de la

neuvième année (*n*=498) et des élèves de douzième année avec des antécédents curriculaires différents (*n*=698), et 93 professeurs de biologie employés au Portugal. Tandis que les recherches précédentes sur les perceptions des étudiants se sont, principalement, concentrés sur des éléments discrets tels que les connaissances et attitudes ; dans ce projet, une analyse multidimensionnelle a été effectuée en considérant ces concepts, ainsi que des éléments motivationnels. Les donnés recueillis indiquent que les perceptions des étudiants et les intentions comportementales sont modulés par des facteurs cognitifs, affectifs et motivationnels. La plupart des étudiants, surtout les élèves de neuvième année et les élèves de douzième année n'ayant pas de sciences dans leur curriculum, reconnaissent l'importance de la biotechnologie et démontrent des attitudes positives à l'égard de la plupart des applications, mais présentent des connaissances limitées et n'étaient pas intrinsèquement motivés pour rechercher des informations à propos du sujet. Les connaissances, attitudes, intérêts et importance attribuées à la biotechnologie par les étudiants ont été positivement corrélés.

En ce qui concerne les professeurs, leurs opinions sur la biotechnologie furent positives, quelle que soit leur âge, expérience d'enseignement et qualifications. Les professeurs ont, néanmoins, surestimé les limitations pratiques de l'éducation en biotechnologie, surtout en ce qui concerne les limitations matérielles et de ressources, qu'ils n'ont pas jugée nécessaire de surmonter. Il a aussi été noté que l'actuelle disponibilité de ressources éducationnelles innovatrices était fortement inexplorée par ses professeurs.

Globalement, ses résultats suggèrent que, pour aller à l'encontre des demandes des étudiants et des professeurs, il est nécessaire de développer des activités qui : i) sont basées sur des contenus informatifs, pertinents et récents ; ii) encourager le développement de compétences réflexives et de pensées d'ordre élevée ; iii) sont faciles et rapides à planifier et à implémenter ; et iv) exigent des matériaux simples et peu coûteux.

D'après ses critères, un ensemble d' activités, adressant plusieurs questions pertinentes de santé publique, comme la résistance aux antibiotiques et le sujet curriculaire qu'est la production d'antibiotiques, ont été développées, optimisées, et implémentées dans un environnement scolaire informel faisant partie de l'Université Junior de Porto (http://universidadejunior.up.pt/) (*n*=42), et dans un contexte formel de l'école secondaire, faisant partie des classes d'étudiants de biologie de la douzième année (*n*=147, de sept classes de biologie et leurs professeurs). L'efficacité des activités a été évaluée par un mixage de méthodes basées sur un dessein pré/post avec l'utilisation d'exogroupes dans un contexte scolaire.

Dans les deux situations, les résultats obtenus démontrent que les participants ont développé une sensibilité et une compréhension à propos de la résistance aux antibiotiques, et une conscientisation accrue sur l'importance d'un usage judicieux des antibiotiques. Il y eut, aussi, des améliorations significatives dans leurs compétences de procédure. Les étudiants ainsi que les professeurs ont souligné la pertinence et l'utilité des activités pour la promotion, l'engagement et la motivation de l'apprentissage. La plupart conviennent que des activités pratiques, quand elles sont contextualisées dans des topiques significatifs et vont de pair avec le curriculum, présentent une contribution précieuse pour atteindre des objectifs académiques et personnels.

Dans un plan plus général, les résultats de ce travail démontrent que l'efficacité du travail pratique est sous-jacente à un réseau de facteurs qui interagissent entre soi, comme la situation d'intérêt individuel de l'étudiant, la conception éducative de l'activité considérée, et la quantité d'orientation et de structuration fourni.

Les implications des résultats de ses recherches vont au-delà de l'éducation de la biotechnologie, ils fournissent une preuve poignante de la valeur éducationnelle du travail pratique qui informe la recherche sur l'éducation de la science. Les indicateurs transmis ici renforcent le besoin d'évaluer de façon critique les effets des activités pratiques, et préparent la voie pour l'arrangement de politiques d'enseignement rectificatives. En outre, et peut-être plus important, ces résultats accentuent le besoin d'inciter une prise de conscience et de responsabilité de la part des élèves, quand ils sont appelés à prendre des décisions basées sur des fondements scientifiques.

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Abbreviations

DEB – Departamento de Educação Básica

DGIDC – Direcção-Geral de Inovação e de Desenvolvimento Curricular

DNALC – DNA Learning Center

EACEA – Education, Audiovisual and Culture Executive Agency

EARLI – European Association for Research on Learning and Instruction

EB – Eurobarometer

EFA – Exploratory factor analysis

EIBE – European Initiative for Biotechnology Education

ERIDOB - European Researchers in Didactics of Biology

EV – Eigenvalue

FCT – Fundação para a Ciência e a Tecnologia

GM – Genetically modified

GSJ – Garlic shoot juice

KMO – Kaiser-Meyer-Olkin

KR20 – Kuder-Richardson formula 20

NABT – National Association of Biology Teachers

NCBE – National Center for Biotechnology Education

NCBI - National Center for Biotechnology Information

NRC – National Research Council

NSES – National Science Education Standards

OECD – Organisation for Economic Co-operation and Development

PCA – Principal component analysis

PCR – Polymerase chain reaction

PISA – Programme for International Student Assessment

SAS – Statistical Analysis System

SPSS - Statistical Package for the Social Sciences

SSI – Socioscientific issues

STS – Science-Technology-Society

STSE – Science-Technology-Society-Environment

S&T – Science and Technology

UJR – Porto's Junior University

UV – Ultra violet

CHAPTER I

General Introduction

Chapter I

General introduction

Biotechnology and its impact on society

Biotechnology can be broadly understood as a field of applied biology involving the use of living beings and/or their components, as well as bioproducts or bioprocesses to produce useful products, usually with a commercial purpose. The term biotechnology was first coined in 1919 by Hungarian engineer, Karl Ereky, to describe the intensive production of pigs; he then generalized the term to encompass all industrial processes, through which commercial products are produced from raw materials with the intervention of microorganisms (Bud, 1994; Saini, 2010; Shmaefsky, 2006). Currently, several definitions have been proposed, namely (Saini, 2010; Shmaefsky, 2006):

"The use of living things to make products" – *American Association for the Advancement of Science* (http://ehrweb.aaas.org/ehr/books/glossary.html#biotechnology)

"Any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use" – *Convention on Biological Diversity* (http://www.cbd.int/convention/articles/?a=cbd-02)

"The integration of natural sciences and engineering in order to achieve the application of organisms, cells, parts thereof and molecular analogues for products and services" – *European Federation of Biotechnology (*http://efbpublic.org/Members/admin/library/Library_Card.2004-04-04.8524178223)

"The application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services" – *Organization for Economic Cooperation and Development (OECD)* (http://www.oecd.org/document/42/0,3746,en_2649_34537_1933994_1_1_1_1,00.html)

It is interesting to note that, although biotechnology is often narrowly associated with genetic engineering, it comprises a varied range of processes and methodologies, many of which predate the current formal applications of science and technology (Fitzsimmons, 2007; Saini, 2010). Paradoxically, while biotechnology is among the youngest sciences and a rapidly increasing technical discipline which has experienced more advancement in the last decades than most of the other fields of science (Shmaefsky, 2006), taken in its wider sense, biotechnology procedures have been used by humans since prehistoric times, going back to early agriculture practices involving the domestication of animals and the cultivation of plants for food production (Bud, 1994; Fitzsimmons, 2007; Saini, 2010). In fact, different civilizations have been known to use specific microorganisms and/or byproducts to make cheese, beverages, and bread by fermentation. For instance, Sumerians and Babylonians used yeast to make beer and wine, while the Egyptians used these microorganisms to make bread. Meanwhile, in ancient China and India, lactic acid bacteria were being used to produce yogurt and other dairy products (Bud, 1994; Saini, 2010).

Biotechnology applications extend beyond the range of agriculture and food production. In 1917, Chaim Weizman found that the bacterium *Clostridium acetobutylicum* had the ability to convert corn starch into acetone, which was used to produce explosives during World War I. In 1929, Alexander Fleming isolated penicillin, the first antibiotic compound identified, from the fungus *Penicillium notatum* (Saini, 2010).

More recently, in the second half of the 20th century, with the advent of modern biotechnology prompted by advancements in the fields of molecular biology and genetic engineering, biotechnology has been hurled into a whole new and wider dimension. The unprecedently rapid pace at which modern biotechnology is evolving has provided numerous and significant contributions for human welfare, mostly regarding biomedical innovations, but also in industrial and agro-food fields (Saini, 2010; Shmaefsky, 2006). Modern biotechnology applications can be grouped according to countless criteria, given their diversity concerning, for instance, the techniques used, the organisms manipulated, or the end-product or service. A popular categorization that has been used in the Eurobarometer (EB) refers to green, red and white biotechnology as relating to the application of biotechnology to the fields of agriculture, medicine, and the environment, respectively (Gaskell et al., 2006; Schüler, 2006). Within each of these divisions, further distinctions can be made to embrace the specialties envisioned by other classifications, such as the European Community's platform-based categorization system, which considers 15 divisions, ranging from the "Animal Cell Technology Industrial Platform" to the "*Bacillus subtilis* Genome Industrial Platform" (Shmaefsky, 2006) (Fig. I.1).

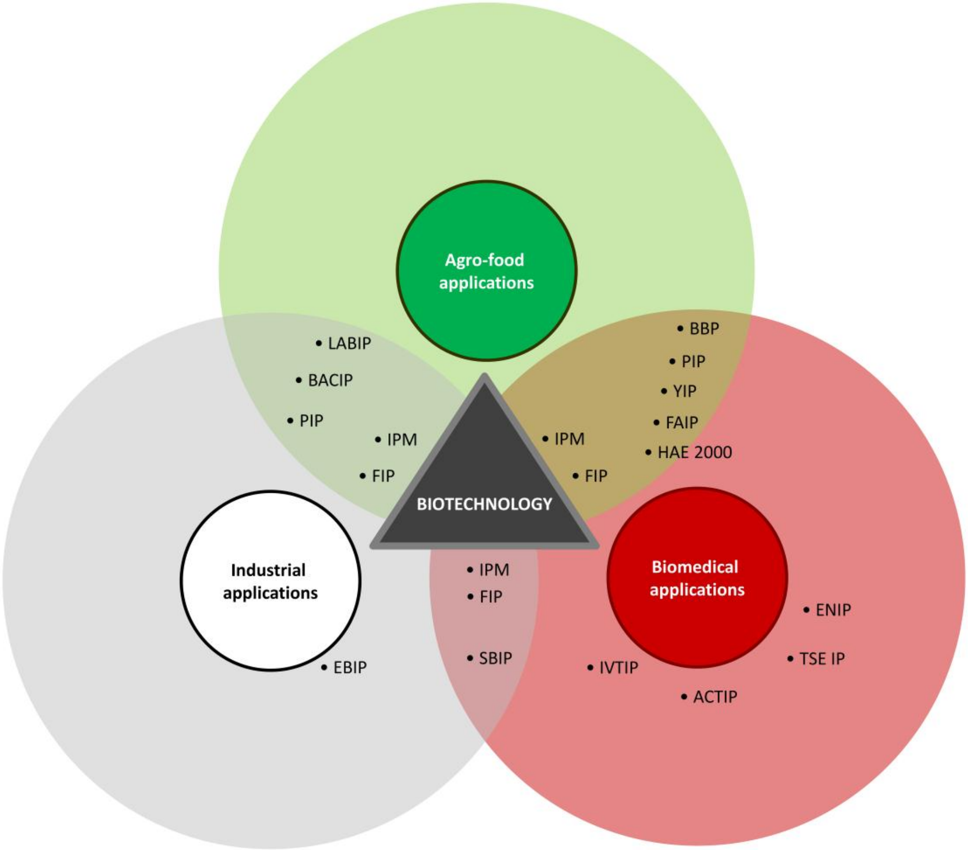

Fig. I.1. A possible categorization of biotechnology applications.
Applications in the fields of agriculture, medicine, and the environment are classified as green, red and white biotechnology, respectively (Gaskell et al., 2006; Schüler, 2006). The 15 platforms proposed by the European Community (Shmaefsky, 2006) are represented within this classification system. ACTIP – Animal Cell Technology Industrial Platform, LABIP – Lactic Acid Bacteria Industrial Platform, YIP – Yeast Industry Platform, PIP – Plant Industry Platform, IVTIP – In Vitro Testing Industrial Platform, BACIP – Bacillus Subtilis Genome Industrial Platform, FAIP – Farm Animal Industrial Platform, IPM – Industrial Platform for Microbiology, SBIP – Structural Biology Industrial Platform, BBP – Biotechnology for Diversity Platform, FIP – Fungal Industry Platform, ENIP – European Neuroscience Industrial Platform, EBIP – Environmental Biotechnology Industrial Platform, TSE IP – TSE Industrial Platform, HAE 2000 – Healthy Ageing Europe Industrial Platform.

Green biotechnology includes agro-food applications, namely the production of transgenic plants, molecular farming, functional food development, and livestock breeding. Red biotechnology includes the development of pharmaceutical drugs, gene therapy, tissue engineering, pharmacogenomics, system biology, and other biomedical applications. White biotechnology deals with the application of biotechnology processes to environmental and industrial production. Examples of these applications include enzyme production, environmental diagnostics, bioremediation, and bioenergy. Not surprisingly, given the transversal nature of many of the procedures and techniques used, these classification systems are not static and the same application can fit into more than one category. For example, innovative bioinformatics tools are currently used for different purposes across several fields.

Likewise, due to its multidisciplinary character, biotechnology demands expertise from various areas, including biology, chemistry, physics, mathematics, and computer science, among others (Shmaefsky, 2006). Moreover, unlike other scientific and industrial topics, biotechnology is highly dependent on the development of commercial products with benefits for human and environmental health (Malinowski & Arnold 1999; Shmaefsky, 2006). Biotechnology is mainly developed within an industrial context, and the research carried out relies considerably on technology transfer (Ganguli, Prickril, & Khanna, 2009; Shmaefsky, 2006). In fact, biotechnology's numerous achievements have had beneficial implications for human welfare whose worth has been consistently demonstrated (Fitzsimmons, 2007; McGloughlin, 2006). Biotechnology applications involving the production of "Bt crops", expressing *Bacillus thurigiensis* anti-insect toxin, viral-resistant tobacco, or herbicide-resistant soybean have the potential to decrease our dependency on pesticides (Bock, 2007; Helton, Zhao, & Roush, 2002; Jauhar, 2006). Golden rice (rich in vitamin A), and the use of nitrogen-fixing plant-growth promoting rhizobacteria can contribute to enhanced production yields (Beyer et al., 2002; Jauhar, 2006). In addition, the production of crops with reduced vulnerability to environmental stress, such as salt and drought tolerant crops can allow for the use of otherwise unfertile lands. At an industrial level, microorganism manipulation and cultivation techniques have been associated with promising outcomes concerning the brewery and bakery industries, but also in bioenergy production and environmental conservation (Montgomery, 2003; Rittmann, 2006). Finally, it is in the biomedical field that the impact of biotechnology has been more visible and has attracted more public attention. State of the art molecular biology and genomics techniques have granted the chance to conduct more reliable and efficient medical diagnoses and, in some cases, treatment of genetic disorders. For instance, synthetic insulin and human factors VII and IX are used in the treatment of diabetes and haemophilia, respectively. Other applications include regenerative medicine and organ transplantation, and the production of other hormones, amino acids, vaccines, antibiotics and other compounds with prophylactic and therapeutic interest (Schuler, 2006). It is estimated that global revenues for the biotechnology industry within the public sector in 2010 were close to US $80.6 thousand millions, and that genetically engineered drugs account for 9% of the total global prescription drugs market, representing approximately US $880 thousand millions during 2011 (Plunkett, 2012)

The previous examples, added up to all the existing applications, sustain the environmental, social and economic benefits of biotechnology. This has led scientists, politicians, decision-makers and other stakeholders to agree on biotechnology's extraordinary potential, and some to consider that it can pave the way for a biochemical revolution (Amin, Jahi, Nor, Osman, & Mahadi, 2007; Scheitle, 2005; Shmaefsky, 2006). However, the powerful potential of modern biotechnology goes hand in hand with the controversy surrounding its applications. Issues such as stem cell research, cloning and the production of transgenic organisms are constantly challenging public opinion, as the rapid advancements of biotechnology outpace the public's ability to keep up-to-date with the progress in this scope and with the societal meaningfulness of biotechnology applications (Shmaefsky, 2006; van Eijck 2010). Even the scientific community finds itself often divided concerning the expectable implications and limitations of biotechnology (Brossard & Nisbet, 2005; Hoover, Brown, Averick, Kane, & Hurt, 2009), which is not surprising given the uncertainty that naturally stems from such a fruitful and demanding area of research, whose potential is yet to be fully harnessed.

It has been argued that a major factor contributing to the controversy with which biotechnology has been associated is the neglect of the public's needs and interests (Amin et al., 2007; Sagar, Daemmrich, & Ashiya, 2000). Understanding the general public's perceptions and positioning concerning biotechnology is of the utmost importance for a knowledge-based society in which citizens are expected to participate in democratic decision-making processes regarding science and technology. Particularly considering that public acceptance of biotechnology applications can promote or hinder the acceptance and commercialization of novel technological products (Canavari & Nayga, 2009; Kamaldeen & Powell, 2000; Magnusson & Hursti, 2002; Moerbeek & Casimir, 2005). The acknowledgement of the need to understand public opinions and perceptions about biotechnology has motivated numerous studies along the years in countries all over the world.

Public perceptions about biotechnology

The relevance of gauging public perceptions about biotechnology was first recognised in the late 1980s (Gaskell et al., 2003), and ever since, through extensive survey-based studies. A paradigm of such studies is the series of EB surveys, which every three years since 1991 have been assessing the attitudes of the European people towards biotechnology and life sciences. Based on the analysis of the time series data provided over this period, Europeans seem to have been growing more optimistic about biotechnology (Gaskell et al., 2010). In comparison with earlier years, there is a noticeable support for novel and sustainable technologies, namely related with biofuel production, and an increased willingness to trust the government and the industry, coupled with a more balanced appraisal of the benefits, risks and limitations of technological applications (Gaskell et al., 2010). However, these general tendencies must be interpreted in light of previous indicators about the public's reactions towards biotechnology and the factors that influence those reactions. In fact, over the years, public perceptions of biotechnology have diverged considerably, particularly in what concerns biomedical and agro-food applications. Consumer acceptance of modern biotechnology products and services has been shown to vary according to the type and purpose of the application or the organism manipulated (Canavari & Nayga, 2009; Einsiedel 2005; Sagar et al., 2000). In addition, the approval of biotechnology applications depends upon factors such as the perceived risks involved, moral concerns, familiarity with the technology, or the trust in the institutions/agents considered, as well as socio-demographic features (Amin et al., 2007; Canavari & Nayga, 2009; Davies & Phillips, 2006; Finucane & Holup, 2005; Kamaldeen & Powell, 2000; Knight, 2007; Miles, Ueland, Oslash, Øydis, & Frewer, 2005; Sagar et al., 2000; Scully, 2003; Sturgis, Cooper, & Fife-schaw, 2005). This is illustrated in the following examples.

Studies have shown that biomedical applications are usually associated with high receptivity levels, while the opposite tends to happen with agro-food applications (Canavari & Nayga, 2009; Costa-Font, Gil, & Traill, 2008; Kamaldeen & Powell, 2000; Frewer et al., 2004; Grimsrud, McCluskey, Loureiro, & Wahl, 2004; Knight 2007). For many people, the anticipated benefits of genetic testing for medical diagnosis or cell and tissue culturing for therapeutic purposes, are perceived as outweighing the associated risks (Gaskell et al., 2006; Savadori et al., 2004). Conversely, the production and commercialization of genetically modified (GM) food is often received with dismay and uncertainty (Finucane, 2002; Huffman, Rousu, Shogren, & Tegene, 2004; Klerck & Sweeney 2007; Miller & Conko, 2005; Miles et al., 2005; Verdume &

Viaene, 2003), in spite of recently reported increases in the public's intention to purchase this type of foods or food containing GM ingredients (Gaskell et al., 2003).

In the case of human cloning, it was observed that whereas therapeutic cloning is usually considered acceptable, most people disapprove of reproductive cloning (Concannon, Siegel, Halverson, & Freyermuth, 2010; Nisbet, 2004; Shepherd et al., 2004). Concerning the controversial topic of stem cell research, its high disapproval rate has been linked to the tendency for it to be associated with human embryo research, which raises serious ethical issues, namely related with the moral status of human embryos (Einsiedel et al., 2009; Ho, Brossard, & Scheufele, 2008; Lindahl, 2009; Nisbet, 2004). Likewise, applications involving the genetic manipulation of animals are usually disapproved of, because the procedures tend to be regarded as risky and morally unacceptable (Amin et al., 2007: Einsiedel, 2005; Lindahl, 2010).

Gender has also been shown to influence public perceptions. In general, females are described as less interested and accepting of biotechnology than men (Kamaldeen & Powell, 2000; Moerbeek & Casimir 2005; Siegrist, 2000), although this depends on the type of application considered. For example, whereas females seem to be less accepting of applications involving genetic manipulation (Moerbeek & Casimir 2005; Prokop, Lesková, Kubiatko, & Diran, 2007), they appear to be more optimistic than males regarding human embryo research (The Gallup Organization, 2009).

The trust in transnational and national regulatory entities also impacts public perceptions of biotechnology applications (Cantley, 2004; Kamaldeen & Powell, 2000; Siegrist, 2000). Since its inception, and even before entering the public domain, the implications of biotechnology have concerned the scientific community, who in 1974 imposed a self-moratorium on research determining the need to clarify risks associated with its impact on public health and environment. However, this moratorium was not upheld for long, as it was overshadowed by the technology's economic benefits (Gaskell et al., 2003; Murphy & Yanacopulos, 2005). By this time, the public tension surrounding biotechnology applications was already installed, and continued to increase as biotechnology developed and diversified, reaching its peak in Europe between 1996 and 1999 (Gaskell et al., 2003). The level of controversy slowly decreased following the introduction of the European Directives on GM crops and on deliberate releases of GM organisms into the environment, in 1999 and 2001, respectively, which resulted in a more transparent legislative policy. In general, and to this day, the regulation of biotechnology has been set on the basis of precautionary measures. The approval of any given procedures or products depends on a rigorous and exhaustive assessment of not only their improved features, but also their environmental, sanitary and/or health impact (Dąbrowska, 2004; Cantley 2004; Gaskell et al., 2003; Murphy & Yanacopulos, 2005; Pelletier, 2006; Todt, 2004).

Media coverage of biotechnology-related issues also plays an important role in shaping public opinion (Gutteling, 2005; Ho et al., 2008). Biotechnology has been a prominent topic in media news, which frequently herald contentious and polarized views held by opponents and proponents of its applications (Gutteling, 2005; Petersen, 2005) and highlight breakthroughs, and controversies, as for instance the sequencing of the human genome and the debate on the patents and commercial rights of GM seeds (Huffman et al., 2004).

Modern biotechnology is a salient and complex issue that requires knowledge about concepts and processes that are not straightforward for non-experts (Amin et al., 2007; Falk, Brill, & Yarden, 2008). Considering that individuals often rely on information processing short-cuts and on interpretative guidelines made available by information sources they perceive as reliable (Brossard & Nisbet, 2007; Ho et al., 2008), it is necessary to promote the general public's ability to overcome the controversy surrounding biotechnology and engage in informed, participative public debate (Bonfadelli, 2005; Braun & Moses, 2004; Dawson, 2007; Santucci, Mini, Ferro, Martelli, & and Trabalzini,, 2004).

Common citizens develop their knowledge about science and technology mainly through their formal education and based on information conveyed by media sources (Bonfadelli, 2005; Braun & Moses, 2004). Hence, the investment in an efficient science education is essential to empower students, as future engaged citizens, to be actively involved in public dialogue and decision-making processes about science. Not surprisingly, in the context of internationally and nationally acclaimed calls for public participation in personal and civic science-related matters (Einsiedel, 2008; European Comission, 2002), the concerns about public awareness and understanding of biotechnology have spread to the educational field (Fitzsimmons, 2007; Harms, 2002).

Biotechnology education: curricular framing and educational resources

Among the numerous studies addressing public perceptions of biotechnology, some have focused specifically on young people's knowledge and attitudes (Dawson, 2007; Klop &

Severiens, 2007; Prokop et al., 2007; Sáez, Niño, & Carretero, 2008; Uşak, Erdogan, Prokop, & Özel, 2009), although this remains a comparatively under-researched area (Prokop et al., 2007).

The outcomes of these studies reiterate the need to promote biotechnology education, by drawing a picture of superficial knowledge and misperceptions amongst the younger population segments (Dawson, 2007; Prokop et al., 2007, Uşak et al., 2009). Although data in the 2009 Flash EB Series #239 report (The Gallup Organization, 2009) point towards young European's increased awareness and interest about science and technology in general, in various countries and at different instructional levels, students' knowledge about biotechnology-related concepts and procedures has been classified as limited and often erroneous. For instance, in 2007, Dawson reported that Australian high school students, specially the younger ones, had difficulties in defining and providing examples of biotechnology and were particularly unaware of agro-food applications (Dawson, 2007). Prokop and colleagues noticed that Slovakian students' knowledge about the meaning of genetic engineering was poor (Prokop et al., 2007). Turkish students, although relatively aware of practical applications, have been shown to possess an insufficient understanding about basic biotechnology processes involved in DNA manipulation (Uşak et al., 2009). These and other studies have also looked into students' attitudes and how they might relate to knowledge, providing varying results (Dawson, 2007; Klop & Severiens, 2007; Lamanauskas & Makarskaitė-Petkevičienė, 2008; Prokop et al., 2007; Uşak et al., 2009). To some extent mirroring what has been observed in adult populations, students' attitudes towards biotechnology, mostly measured as acceptance and approval of applications, are known to vary from skeptic responses and utter dismissals to an outright support, according to features such as age, gender, or level of education (Dawson, 2007; Klop & Severiens, 2007; Sáez et al., 2007; Prokop et al., 2007; Uşak et al., 2009). In addition, these variations have not been univocally associated with the level of understanding about the underlying concepts (Dawson, 2007; Prokop et al., 2007; Uşak et al., 2009).

As argued by several researchers, the observed literacy deficits can be ascribed to the complexity resulting from the multidisciplinary, sophisticated and abstract nature of the knowledge required to understand biotechnology processes and implications (Amin et al., 2010; Dawson, 2007; Shmaefsky, 2006). This assumption is consistent with the increasing number of studies identifying misconceptions about the notion of microorganism and difficulties in understanding molecular biology and genetics concepts (Harms, 2002). This stresses the importance of enhancing the efficacy of educational measures to promote biotechnology learning and teaching.

The acknowledgement of the relevance of biotechnology education has led to the curricular integration of biotechnology-related topics in many countries, namely the UK, New Zealand, Australia and the USA (France, 2003; Hanegan & Bigler, 2009; Steele & Aubusson, 2004). Furthermore, numerous educational resources and initiatives have been developed to promote students' scientific literacy, many of which include practical activities and lab exercises protocols, made available in scientific and teacher-oriented publications (Costa, 2007; Fisher & Mintz, 2000; Hamilton et al., 2006; Longtin, Guilfoile, & Asper, 2004; Milne & Morrison, 2007; Phillips, Robertson, Batzli, Harris, & Miller, 2008; Rothhaar, Pittendrigh, & Orvis, 2006; Santucci et al., 2004; van Mil, Boerwinkel, Buizer-Voskamp, Speksnijder, & Waarlo, 2010) and also on online platforms.

For instance, assumed to be "the first school biotechnology centre in the world", the National Centre for Biotechnology Education (NCBE) has been providing teachers and schools with innovative educational materials since its establishment in 1984-85 (http://www.ncbe.reading.ac.uk/). Based at the University of Reading, UK, the NCBE has endeavoured to translate its materials into several languages, including German, French and Danish. The NCBE also organises workshops for teachers and sells equipment and materials to be used in the development of the protocols proposed. The Centre was also involved in the conception of the European Initiative for Biotechnology Education (EIBE). Founded in 1991, EIBE's purpose is to "…promote skills, enhance understanding and facilitate public debate throughout Europe". This European multidisciplinary network, composed by biotechnology education experts from 20 centres in 17 European countries, has as its main activity the development of teaching materials for 16-19 year olds that are now easily available online (http://www.eibe.info/). Another example is the DNA Learning Center (DNALC), a science centre exclusively dedicated to genetics education. Operating at Cold Spring Harbor Laboratory, USA, a reference research institution at the forefront of molecular biology and genetics, the DNALC sets its goal as preparing "students and families to thrive in the gene age". On the centre's website (http://www.dnalc.org/), it is possible to find numerous resources intended for postgraduate, college, precollege, and general public levels. Business-oriented companies, such as Bio Rad (http://www.bio-rad.com/) or Carolina (http://www.carolina.com/), in addition to laboratory supplies and equipment, provide educational kits and hands-on protocols for biotechnology and molecular biology-based activities. Many more examples could be mentioned, some of which are highlighted in Table I.1.

Table I.1

A selection of educational resources developed for the promotion of biotechnology education. Highlighted are diverse laboratorial and web-based activities available in internationally acknowledged web sites with open access. These activities include understandable and structured scientific information and virtual laboratories, with simulations of laboratorial work.

ACTIVITY/RESOURCE	SOURCE
The transgenic fly virtual lab Authorship: Howard Hughes Medical Institute	 http://www.hhmi.org/biointeractive/vlabs/transgenic_fly/index.html
The Virtual Lab Book. Includes: Using bacteria in Molecular Biology; Restriction digestion and agarose gel electrophoresis; Polyacrylamide gel electrophoresis; Polymerase chain reaction Authorship: Stephanie Dellis. College of Charleston	 http://delliss.people.cofc.edu/virtuallabbook/
The Lambda DNA Protocol, The Transformer Protocol, Investigating Plant DNA, Illuminating DNA, Practical Biotechnology, Nature's Dice, Plant Tissue Culture Authorship: National Centre for Biotechnology Education – University of Reading	 http://www.ncbe.reading.ac.uk/
Microbes and molecules, DNA profiling, Issues in human genetics, Transgenic animals, Biotechnology and the environment, … Authorship: European Initiative for Biotechnology Education (EIBE)	 http://www.eibe.info/
Detect Genetically Modified Food Authorship: Diana Brandner, Bio-Link	 http://www.bio-link.org/home/resources/guides/genetically-modified-food
DNA from a Fruit Smoothie, Genetically Modified Foods Authorship: The Biotechnology Project at Madison College, Biotechnology Department at Madison Area Technical College in Madison	 http://matcmadison.edu/plus/biotech/laboratory-activities

In spite of this evident investment in the design of teaching materials, their efficacy is sparsely characterised, due to the lack of robust indicators of their educational impact. Nevertheless, the few studies that have been carried out with this scope have conveyed promising results. For example, Phillips et al. (2008) showed that students' understanding of concepts related to polymerase chain reaction (PCR) and gel electrophoresis can be enhanced by aligning laboratory work with exercises to promote critical thinking. Similarly, in 2010, Klop and co-authors reported the beneficial effects of a science education module on genomics and cancer research in promoting student awareness and positive attitudes towards biomedical applications (Klop, Severiens, Knippels, van Mil, & Ten Dam, 2010). This suggests that it is possible to positively influence students' perceptions of biotechnology, and further emphasizes the relevance of conducting systematic and thorough assessments of the impact of biotechnology-related educational resources on students' scientific literacy.

Biotechnology education in the Portuguese elementary and high school science curricula

Like in many other countries, the Portuguese science curriculum also addresses biotechnology topics. The coverage of these topics is mainly allocated to the last year of the elementary natural sciences curriculum (9^{th} grade), and to the 12^{th} grade biology program. As illustrated in Table I.2, several resources have been developed or adapted by Portuguese teams to assist in promoting biotechnology education at pre-university levels.

Biotechnology education in the elementary science curriculum (9^{th} grade)

Until 2009/2010 school year, compulsory schooling in Portugal comprised nine years of elementary education organised in three cycles of four, two and three years. As from 2009/2010, it was extended to include three more years of secondary education, referred to as high school, for the purpose of this thesis (Lei 85/2009, 29 de Agosto). Upon entering high school students are required to choose the area in which they wish to major, which may or may not include science and technology subjects. Hence, for many students, formal science education ends once they finish the 9^{th} grade. This emphasises the importance of developing educational activities specifically intended for implementation at elementary school levels, in Portugal. Until 2011 (Decreto-Lei 17169/2011, 23 de Dezembro), the national curriculum for elementary education was organised according to essential and specific competencies (Departamento de Educação Básica [DEB], 2001a). The first category concerns transversal and interdisciplinary skills that should be developed in an integrated way for the various subjects considered, and the second category refers to particular skills associated with a given subject. Concerning the specific competencies envisioned for the natural and physical sciences, the curriculum highlighted that "the role of science and technology in our everyday lives demands a population with sufficient knowledge and understanding to grasp and follow debates on scientific and technological topics, and get involved in the issues raised by those topics" (DEB, 2001a; p. 129). Maintaining the importance of considering the students' background, it was clarified that "scientific knowledge was not attained simply through everyday situations" (DEB, 2001a; p. 129), and that there was a need for "the teacher's planned intervention and responsibility for consolidating knowledge according to the students' age and the school context" (DEB, 2001a; p. 129). In this regard, it was also recognised that the information about science-related issues "… is more frequently made available by the media than by the school" (DEB, 2001a; p. 129). Science education at these educational levels was regarded as an initial training that should motivate and interest the students about science and the natural world.

By the end of elementary education, students were expected to have developed competencies in four domains: *knowledge* (conceptual - understanding *what is science*, its advantages, consequences and limitations; procedural - understanding *how science is done*, its processes and methods; epistemological - understanding *about science*, the evolution of scientific knowledge, its advancements and drawbacks); *reasoning* (critical and creative scientific reasoning); *communication* (making use of scientific terminology to share and discuss results and conclusions); and *attitudes* (curiosity, perseverance, reflection, respect and critical positioning). To allow developing these competencies, the curriculum integrated four themes (*Earth in space*, *Earth in transformation*, *Sustainability on Earth*, and *Living Better on Earth*), supported on the integrative backbone *Science-Technology-Society-Environment* interaction, in compliance with currently acknowledged curricular frameworks (Auler & Delizoicov, 2006; Bennett, Lubben, & Hogarth, 2007; Cabo Hernández, Enrique Mirón, & Cortiñas Jurado, 2006; Dawson & Venville, 2010; Klosterman & Sadler, 2010; Nahum, Ben-Chaim, Azaiza, Herskovitz, & Zoller, 2010; Praia, Gil-Pérez, & Vilches, 2007; Zeidler, Sadler, Applebaum, & Callahan, 2009; Zeidler, Sadler, Simmons, & Howes, 2005).

Table I.2

Selection of resources developed by Portuguese authors to promote students' scientific literacy on biotechnology-related topics

Activity/Resource	Source
Biorremediação – microrganismos em acção, Identificação de um criminoso por perfil de DNA, Neurónios degenerados – diagnóstico da doença de Alzheimer, … Authorship: Centro de Ciência Júnior - BIOCANT	 http://www.centrocienciajunior.com/default.asp
Laboratório de Biotecnologia, Transformar e produzir, … Authorship: Centro de Ciência Viva de Tavira	 http://www.tavira.cienciaviva.pt/laboratorios/modulo.asp?accao=showmodulo&id_exp_modulo=3&id_exposicao=2
Extracção de DNA, Amplificação por PCR, Sequenciação de DNA, Expressão de um clone, Pesquisa na Bionet, … Authorship: Pavilhão do Conhecimento	 http://gam.pavconhecimento.pt/pavilhao/press_releases/index.asp?accao=consultar&id_cimprensa=96
A célula com paredes de vidro Authorship: Fábrica – Centro de Ciência Viva de Aveiro	 http://www.ua.pt/fabrica/PageText.aspx?id=3649
Electroforese de Proteínas em Gel de Poliacrilamida, Laboratório Virtual de Genética Authorship: VLabs - Laboratórios Virtuais – Universidade do Minho	 http://vlabs.uminho.pt/biologia/biologia.html
Genes Mutados, Clínica de Reprodução Humana, Reprodução=®Produção?, Bioindicador, … Authorship: Estaleiro da Ciência – Instituto de Biologia Molecular e Celular e Faculdade de Ciências, Universidade do Porto	 http://www2.ibmc.up.pt/moodle2/course/view.php?id=35

The first reference to biotechnology is made in the theme *Living Better on Earth*: "Biotechnology, a relevant area in the scientific and technological society we live in, will be an essential knowledge for the quality of life." (DEB, 2001a; p. 143) The main goal of this theme is to acquaint students with the notion that quality of life is underlined by the concepts of individual and collective health and safety. It is expected that students "acknowledge the need to analyse critically ethical questions related with certain scientific and biotechnology applications; (…) recognise that the decision-making about behaviours related with global health and safety is influenced by socio-cultural and economic aspects; (…) understand that science and technology have contributed to improve the quality of life; and understand how society can and has been steering scientific and technological innovation in the scope of global health and safety" (DEB, 2001a; p. 144). This topic is usually addressed in the 9th grade, in a final and binding stage of the learning taking place throughout elementary education, with the purpose of enhancing the students' awareness about their role in assuring a natural balance at personal and collective levels. In this context, it is suggested the "discussion of contentious issues on which citizens must have support opinions, the (…) evaluation and management of risks and decision-making about issues that affect society, keeping in mind environmental, economic and social factors, and (…) the analysis of controversial scientific positioning (…)", among other learning activities.

The analysis of the elementary science curriculum guidelines (DEB, 2001b) reveals that the diversity of scientific contents to be addressed, together with the multiplicity of educational activities suggested, has the overall goal of "contributing to the promotion of students' scientific literacy" (DEB, 2001b; p.4). While there is not a specific moment in which biotechnology-related contents are purposely mentioned, references are made in the curriculum to educational activities (Table I.3), which include, for instance, reflecting about applications and consequences of genetic manipulation, understanding the contribution of molecular biology to solve problems of the modern societies, and acknowledging several ethical limitations posed by scientific research.

As of the 23rd of December 2011, the document that conveys the essential competencies that students must develop throughout elementary education has been withdrawn (Decreto-Lei 17169/2011) and is expected to be replaced in the near future by another document relying on different terminology and of more instructive character. However, the revised document is not likely to include major differences in what concerns the coverage of biotechnology-related topics. Considering the framing of science classes at elementary school in what concerns schedule and curricular content, biotechnology will expectably remain in the curriculum, seeking to provide students with an overview of main applications and their impact on the quality of life.

Table I.3
Direct and indirect references to biotechnology-related contents in the Portuguese elementary curriculum (DEB, 2001b).

TEXT SEGMENT	SUB TOPIC	PAGE
"Considering the possible contribution of the development of scientific knowledge, namely in Genetics, for solving various problems that concern societies (regarding food and medicine production, medical procedures, family planning, among others), students must have the chance to reflect upon several applications and possible consequences of genetic manipulation"	Transmission of life	34
"The discussion of news in the media (for instance related with cloning, medically assisted reproduction) can contribute to the acknowledgement of some ethical restrictions posed at scientific research."	Transmission of life	34
"This theme is transversal and has been addressed throughout elementary school on different occasions. It can be resumed by deepening specific aspects, essential for understanding and making decisions about issues that challenge society, by debating environmental, economic and social factors."	Science, Technology and Quality of Life	38
"It is suggested the development of projects (…) focused on topics such as: (i) production and use of products (medicines, sun blocks, fertilizers, pesticides, detergents, soaps, cosmetics and transgenic foods) (…) The assignments must evidence the evaluation of the risks and benefits involved."	Science, Technology and Quality of Life	38

Biotechnology education in the high school science curriculum (12th grade biology)

Since the 2005/2006 school year, the biology program for the 12th grade is focused on the general theme: *Biology and today's challenges* (Direcção-Geral de Inovação e de Desenvolvimento Curricular [DGIDC], 2004). This document reflects the Ministry of Education's emphasis on science education, allowing young people to "be prepared to face confidently the scientific and technological issues posed by society, (…), to be capable of outweighing the claims at stake, in order to formulate rational opinions and participate in decision-making processes." (DGIDC, 2004, p. 2). This concern stems from the recognition that society is increasingly confronted with techno-scientific issues with more or less immediate physical, ethical and moral repercussions, namely "the controversy surrounding the manipulation of human gametes and embryos, cloning, the use of individuals' genetic information by employers and insurance companies, the consumption of transgenic foods, the use of experimental medicines or the selection of wastewater treatment processes." (DGIDC, 2004, p. 2).

Contrasting with the elementary science curriculum, the 12th grade biology program clearly emphasises biotechnology, by encompassing molecular biology and genetics concepts and procedures under a technological perspective. In fact, the understanding of concepts and methods related to biotechnology, as well as the critical positioning on risks, benefits and consequences of biotechnology applications are valued as important aspects for citizenry. Accordingly, the references to biotechnology education throughout the program are numerous. It is recommended that the impact of biology and biotechnology is analysed based on "examples of products and services" (DGIDC, 2004, p. 7) and "the reflection about social, economic and ethical aspects that frame their origin and/or influence their applicability" (DGIDC, 2004, p. 7). Students must acknowledge "the relevance of biology and biotechnology nowadays, since they influence people's quality of life and the organisation of societies, by presenting alternatives and raising questions that require decisions to be made at techno-scientific, political, social and ethical levels." (DGIDC, 2004, p. 4). The structure of the subject and the contents addressed are expected to allow the students to develop *conceptual skills* – related to the development of knowledge about science; *procedural skills* - related to the procedures involved in scientific research, at cognitive and manipulative levels; and *attitudinal skills* – related to the features of scientific research and their consequences, such as rigor and perseverance. Among the educational objectives aligned with these competencies, is "the reasoning about various claims (…) with the purpose of forming opinions about social controversies involving biology and biotechnology concepts; the construction of values and attitudes that can lead to balanced decisions about problems involving interactions between science, technology, society and environment; the recognition that the development of knowledge about biology and biotechnology rests on pluridisciplinary and interdisciplinary approaches; the understanding that research on biology and biotechnology is influenced by problems that affect societies at given historic moments, and by interests of political, economic and/or axiological nature; to analyse implications of advancements in biology and its technological applications for the quality of people's lives." (DGIDC, 2004, p. 5).

The program is organised according to five thematic units based on a core problem: *How to improve people's quality of life without compromising the natural resources?* (DGIDC, 2004). From this key question, two other emerge: *"What techno-scientific contributions must we* *accept?"* and "*On which criteria and arguments are decisions made?"*. Biology education is expected to equip students to answer these questions, preparing them to mobilise knowledge about biology and biotechnology into the analysis of issues with social impact. Table I.4 outlines the conceptual structure of the program. Although each unit comprises specific conceptual, procedural and attitudinal contents, the study of biotechnology processes is transversal to the five units.

Table I.4
Conceptual structure of the Portuguese 12th grade biology program (DGIDC, 2004)
To each thematic unit corresponds a core question. The three first questions are the same for the three units.

CORE THEME	PROBLEM	THEMATIC UNIT	CORE THEMES	CORE QUESTIONS
Biology and today's challenges	*How to improve people's quality of life without compromising the natural resources?* *What techno-scientific contributions must we accept?* *On which criteria and arguments are decisions made?*	1	Reproduction and fertility manipulation	What can be done in the scope of reproductive processes?
		2	Genetic heritage	What challenges are posed at genetics?
		3	Immunity and disease control	And to disease control?
		4	Food production and sustainability	How to solve food problems?
		5	Preserve and recover the environment	What solutions for the environmental effects of human activity?

Unit 1: Reproduction and fertility manipulation. This unit addresses biotechnology processes involved in reproductive manipulation, and emphasizes "their importance in the control of the birth rate in human populations and in solving fertility issues." (DGIDC, 2004, p. 7). Students must be able not only to gather and interpret information related to medically assisted reproduction, but also to develop critical and balanced opinions about its use, and about the manipulation of embryonic cells. The discussion about the biological and socio-ethical

implications associated with these processes and "possible contributions to the improvement of the quality of life" (DGIDC, 2004, p. 18) should be encouraged.

Unit 2: Genetic heritage. This unit is based on the study of genes, namely as "evolutionary heritage of species and as objects of biotechnology intervention" (DGIDC, 2004, p. 7). From a conceptual standpoint, one of the topics to be addressed concerns *The basis of genetic engineering*. This unit aims for students to understand the biotechnology processes involved in DNA manipulation, through the analysis of laboratory procedures. It is stated that teachers must highlight "the production of GM organisms through DNA manipulation" (DGIDC, 2004, p. 20). Concerning attitudinal skills to be developed, the unit suggests "the reflection about biological, ethical and social aspects related with the decoding of the human genome" (DGIDC, 2004, p. 19) and the development of "a responsible and critical attitude towards the assertions supporting the debates on the use of cloning and genetic engineering processes applied at humans" (DGIDC, 2004, p. 20). It is also expected that students develop the capacity to be critical and selective regarding the information conveyed in the media about these issues. Methodological suggestions for this unit include: "the interpretation of DNA manipulation procedures and due results" (DGIDC, 2004, p. 22); the "evaluation of the potential of recombinant DNA technology to study human gene expression in laboratory conditions" (DGIDC, 2004, p. 22); the analysis of PCR techniques and their potential and limitations; and "the discussion of situations with social impact about the production of GM organisms" (DGIDC, 2004, p. 22).

Unit 3: Immunity and disease control. In this unit some biotechnology solutions applied in medicine are discussed. One of the conceptual contents foreseen is the role of *biotechnology in disease diagnostic and therapy*. From a procedural perspective, students are expected to be able to select and process information about the use of biotechnology procedures in the production of substances with therapeutic purposes. It is recommended to highlight "the advantages of biotechnologically produced therapeutic substances" (DGIDC, 2004, p. 24), namely antibiotics and steroids. Students must be given the chance to form opinions about the use of animals in biology research and to understand the importance and consequences of science-technology interaction. Very precise methodological suggestions are put forth, as for example research-based assignments and debates about the contribution of biotechnology to the prevention, detection and cure of immune disorders. Some of the topics proposed include:

the use of monoclonal antibodies; “genetic engineering in the production of therapeutic substances (…), in neo-natal disease diagnosis, in transplant organ compatibility assessment, in paternity testing” (DGIDC, 2004, p. 25); and “bioconversion in antibiotic production (…) and steroid production (…)” (DGIDC, 2004, p. 25).

Unit 4: Food production and sustainability. This unit addresses the role of microorganisms and the improvement of enzymatic processes involved in biotechnology methods applied to the agro-food industry, and to plant and animal production and improvement. The first conceptual content refers to the use of microorganisms in food production, and recommends addressing fermentation and enzymatic activity processes. Students must be involved in activities of data gathering and in practical activities about processes related with food preservation. It is important that students learn to build “informed opinions about the use of GM foods” (DGIDC, 2004, p. 26). The second conceptual content refers to the *exploitation of the biosphere’s potential*, through *animal and plant production* and *pest control*. Students must know, analyse and interpret plant cell tissue culture techniques and cloning procedures applied to agriculture and animal production, and also understand their potential and assess their ecological, economic and ethical impact. They should begin to participate in the public discussion about the use of GM organisms in food production and pest control. In this sense, teachers must stress biotechnology’s contribution to mitigate world hunger and the “environmental and health importance of natural pest control methods” (DGIDC, 2004, p. 27). There are many methodological suggestions for this unit, including research-based assignments on topics such as tissue culture, animal production, and biodiversity, and school visits to research laboratories. It is also recommended to provide students with “case-studies that can allow for the understanding of the effect of some pests on cultures (…) and different available solutions (…) to counteract them (…)” (DGIDC, 2004, p. 28).

Unit 5: Food production and sustainability. This unit comprises the analysis of issues related to population growth and the environmental impact of human activity, aiming to identify causes, consequences and concerted actions to mitigate or avoid the harmful effects of human actions allowing to recover and/or to protect the environment. In the scope of biotechnology, it is seen as essential that students acknowledge the importance of “techno-scientific advancements in environmental conservation” (DGIDC, 2004, p. 30). The contribution of microorganisms to “reduce organic matter in residues” (DGIDC, 2004, p. 30), as well as the relevance of recycling and waste treatment, must be highlighted. Students must be informed about and conduct experimental procedures on the contamination of natural resources. On one hand, students must be able to understand and comment the techno-scientific factors affecting human population growth, and on the other to know, value and decide on the measures that have been put forth to reduce their negative impact on nature. It is emphasised that students should be stimulated to look critically at media information about these issues. The methodological suggestions for this unit include organising "a school visit to a water treatment plant, or another type of waste treatment facility" (DGIDC, 2004, p. 32), and to privilege integrated approaches that give students the chance to examine the "contribution of biotechnology regarding the manipulation of fertility, alterations of genetic material, immunity and disease control and food production, in order to clarify its role in solving the problem *how to improve the quality of life of humans?*, that frames the program" (DGIDC, 2004, p. 33).

A conceptual framework for biotechnology education

Scientific literacy and STSE/ SSI approaches

The promotion of scientific literacy is a fundamental endeavour of science education (Dawson & Venville, 2009; Millar, 2006; Rebello, Siegel, Witzig, Freyermuth, & McClure, 2010; van Eijck, 2010). It is widely recognised that in a knowledge-based society, science education must foster the broad and transdisciplinary scientific knowledge required for an active, participative and effective citizenry (van Eijck, 2010). However, the notion of scientific literacy is not a straightforward one, given that the term is often used with different meanings (Dawson & Venville, 2009; Hodson, 2003; van Eijck, 2010). The OECD Programme for International Student Assessment (PISA) defines scientific literacy as the "capacity to use scientific knowledge, to identify questions and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity." (http://www.pisa.oecd.org/). In this light, being scientifically literate means that a person is able to ask and answer questions derived from daily contact with scientific issues and make informed decisions based on scientifically sustained arguments.

Under a socio-constructivist perspective of learning (Matthews, 1998; Scott, Asoko, & Leach, 2007), science education frameworks such as Science-Technology-Society-Environment (STSE) and, more recently, Socio-Scientific-Issues (SSI), sustain the scaffolding of the students' ability to mobilise scientific knowledge into real life situations (Auler & Delizoicov, 2006; Bennet et al., 2007; Cabo Hernández et al., 2006; Dawson & Venville, 2010; Klosterman & Sadler, 2010; Nahum et al., 2010; Praia et al., 2007;; Zeidler et al., 2009; Zeidler et al. 2005). It is intended that more than just gaining a set of baseline knowledge, the students develop an integrated array of competencies and attitudes that allow them to apply that knowledge and face the challenges posed by science and technology (Bybee, & McCrae, 2011; Cachapuz, 2001; Cachapuz, Paiva, & Jorge, 2004; Gardner, Jones, Taylor, Forrester, & Robertson, 2010; Zeidler et al., 2005). Beyond the knowledge about what is science, STSE and SSI perspectives conceptualise students' scientific literacy as the understanding about the processes though which science is done and its consequences and limitations (Hodson, 2003). Students must develop not only theoretical scientific knowledge, but also the ability to reflect critically and reason autonomously about the role and importance of science from social, environmental and economic viewpoints (Bennet et al., 2007; Zeidler et al., 2009; Zeidler et al., 2005). Ultimately, they must be able to interpret and make sense of information about science-related issues made available by different outlets (Julien & Barker, 2009; Ward & Hockey, 2007).

Biotechnology is one of the most publicly discussed socio-scientific issues, i.e. issues associated to societal dilemmas with conceptual, procedural or technical links to science, usually controversial in nature, which can be considered through different perspectives (Sadler & Zeidler 2004). Topics such as production of GM organisms or stem cell research continuously fuel the public debate concerning the risks and usefulness of biotechnology applications. Therefore, it becomes essential to assure that all citizens are able to understand and take part in the discussion that surrounds its social, ethical and economic implications. In this context, science education must enable students to become more knowledgeable about the scientific and methodological bases of biotechnology, so they can understand how it can be successfully applied while respecting basic ethical principles (Fig. I.2).

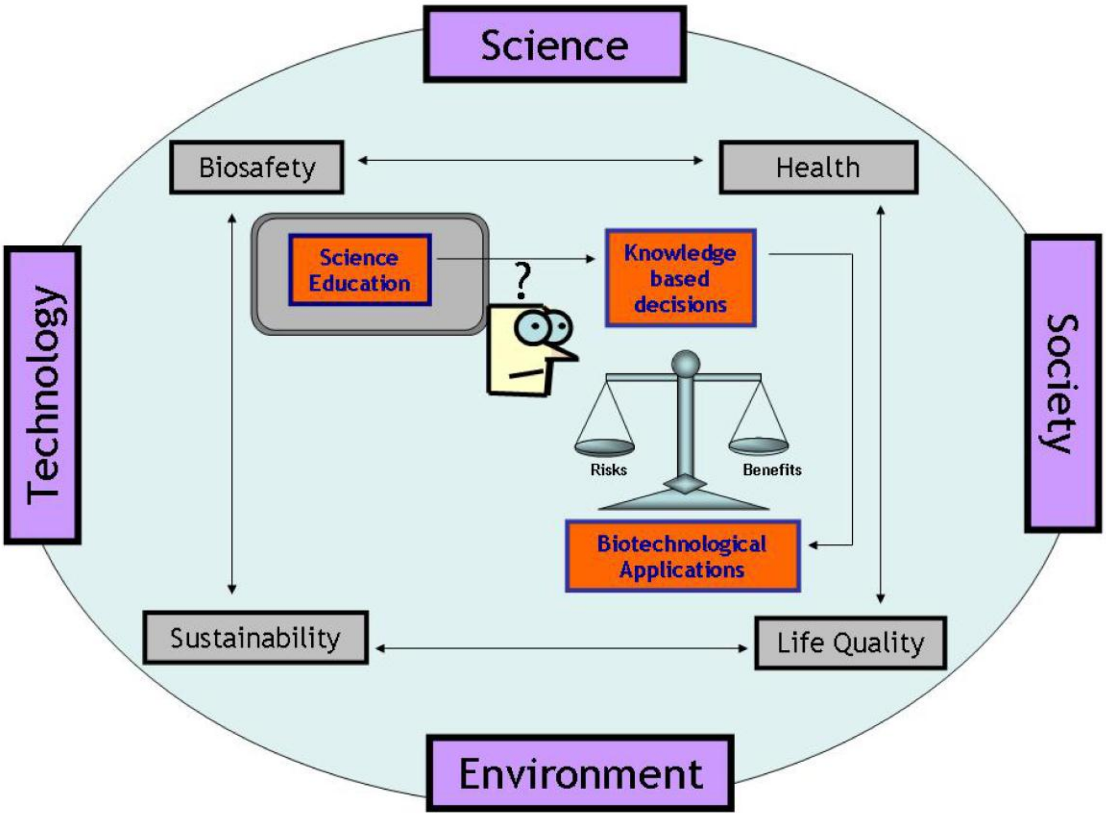

Fig. I.2. Biotechnology education framed within a STSE framework.
In order to be able to make informed and responsible decisions concerning biotechnology applications, citizens must be aware of its risks and benefits, and most importantly, must be able to judge the balance between them. It is mainly through school science education that the students/citizens can develop the competencies to make scientifically sustained choices. This assumes an even greater importance if one realises that biotechnology inevitably affects intertwining dimensions, such as health, life quality, sustainability and biosafety.

Knowledge and understanding, attitudinal responses and motivation towards biotechnology

Modern biotechnology is a complex issue whose understanding and appraisal requires the knowledge of concepts from various disciplines (Amin et al., 2007). Furthermore, besides these cognitive abilities, it is also necessary to develop a set of competencies and values that allow to assess the risks and benefits of biotechnology breakthroughs, and to handle all this information according to personal beliefs and interests (Dawson & Venville, 2010; Holbrook &

Rannikmae, 2007; Kolstø, 2001; Zeidler, Walker, Ackett, & Simmons, 2002). Therefore, when considering the expected and observable impact of biotechnology education on students' perceptions, it is necessary to account not only for knowledge, but also for other elements, such as attitudes and motivation.

Knowledge and attitudes towards biotechnology. Most of the research addressing students' perceptions about biotechnology is focused on knowledge and/or attitudes, frequently investigating the existence of a correlation between them (Chen & Raffan, 1999; Dawson, 2007; Prokop et al., 2007; Uşak et al., 2009), while a more limited number of studies addresses students' interest on this issue (Kidman, 2008; Lamanauskas & Makarskaitė-Petkevičienė, 2008; Weber & Custer, 2005).

Studies focusing on students' knowledge about biotechnology, whether qualitative or quantitative, usually define it as content knowledge about fundamental biotechnology concepts and processes (Dawson, 2007; Prokop et al., 2007; Uşak et al., 2009). These studies investigate, for instance, students' ability to define biotechnology or their understanding of the concepts of genetic engineering and cloning, as well as basic knowledge about genetics and molecular biology (Dawson, 2007; Prokop et al., 2007; Uşak et al., 2009). This literacy is frequently described as insufficient to allow an efficient engagement with biotechnology (Prokop et al., 2007; Uşak et al., 2009).

In what concerns the measurement of students' attitudes, various definitions have been considered, from the perception of risk and benefit, to beliefs or to acceptance and approval (Dawson, 2007; Klop & Severiens, 2007). Not surprisingly, students' attitudinal responses to different applications vary considerably between studies (Dawson, Klop e Severiens, 2007; Sáez et al., 2008). Likewise, the existence of a clear relationship between knowledge and attitudes towards biotechnology has not been utterly demonstrated (Klop & Severiens, 2007; Prokop et al., 2007; Sáez et al, 2008; Uşak et al., 2009). Therefore, it cannot be assumed that improving students' knowledge will necessarily lead to increased optimism and acceptance or to more positive attitudes towards biotechnology.

The underlying cause of the uncertain relationship between knowledge and attitudes may be explained considering the complexity of the attitudinal response. The conceptualisation of attitudes as multidimensional constructs that encompass cognitive, affective and behavioural determinants has led many authors to support a theoretical tripartite model of attitude (McGuire, 1969; Rosenberg & Hovland, 1960). In a study conducted in the Netherlands in 2007, Klop and Severiens demonstrated that this model can successfully integrate the diversity of students' attitudinal responses to biotechnology (Klop & Severiens 2007). In light of this model, and although knowledge can positively influence the cognitive component, the development of a certain attitude towards biotechnology relies on emotional and behavioural elements based on personal weighing of risks and benefits, as well as ethical implications (Brossard & Nisbet, 2007; Savadori et al., 2004; Verdume & Viaene, 2003).

Motivation towards biotechnology. Motivation is a fundamental construct to consider in the field of education, as it is known to influence people's learning and behaviour (Rheinberg, 2005; Ryan & Deci, 2000). According to Ryan & Deci's model (2000), motivational responses are modulated by endogenous and exogenous determinants. Whereas intrinsic motivation can be viewed as a natural interest that predisposes the individual towards something, extrinsic motivation is conditioned by external elements, such as the perception of importance and usefulness of a given object or task. Therefore, when examining students' engagement with biotechnology, it is important to acknowledge the role played by extrinsic and intrinsic motivational elements, such as their interest in biotechnology and the importance that they attribute to it, respectively.

Across Europe, the decline of students following science and technology-based courses has been linked to the unappealing nature of science curricula (OECD, 2006; Osborne & Dillon, 2008). The inclusion of biotechnology in science curricula and the media coverage biotechnology related topics receive, justify the need to evaluate students' interest about this subject (Harms, 2002; Kidman, 2008). The few studies that have addressed students' interest in biotechnology often describe it as limited and gender-associated (Kidman, 2008; Lamanauskas & Makarskaitė-Petkevičienė, 2008; Weber & Custer, 2005). According to recently published data on the EB survey (Flash EB Series No239) young people admit not to be interested in innovations in the fields of GM foods, human embryo research and nanotechnology, although they are aware of them (The Gallup Organization, 2009). While young men seem more interested in nanotechnology, young women display a higher degree of interest in innovations regarding GM foods and human embryo research. Furthermore, specifically regarding how biotechnology is addressed in science curricula, Kidman reported in 2010 that the students' interests may diverge from those of their teachers (Kidman 2010).

Interestingly, regardless of their interest, students often share positive opinions about the importance of biotechnology applications (Elster, 2007; Sjøberg & Schreiner, 2006; The Gallup Organization, 2009). Considering this information, it is important to understand how students' narrowed interest on biotechnology relates to the importance attributed to it.

Therefore, the information made available by correlating interest and importance and assessing their interaction with knowledge and attitudes is important to achieve a sounder appraisal of how students learn about biotechnology and their decision making processes.

Teaching and learning biotechnology through active instructional strategies: the role of practical work

In the context of STSE and SSI approaches to science education, the implementation of educational strategies should favour active learning and teaching methods (Handlesman et al., 2004; Handelsman, Miller, & Pfund, 2006; Michael, 2006; Prince, 2004). Active learning is an umbrella term covering an onset of learner-centred approaches that place on the students themselves the responsibility for their learning (Bransford, Brown, & Cocking, 2000; Handlesmann et al., 2006). In contrast with more traditional teaching methods, active teaching shifts the focus of instruction from the teacher to the students, seeking to engage the students in the learning process as a way to enhance their learning (Bransford et al., 2000; Handlesmann et al., 2004; Handlesmann et al., 2006; Prince, 2004). Among the various types of active learning methods available, inquiry-based learning has been given overarching attention in elementary and high school science curricula around the world (Abd-EL-Khalick & Akerson, 2004; Cuevas, Lee, Hart, & Deaktor, 2005; Sandoval, 2005; Toplis, 2011). Inquiry-based activities are expected to bring students' learning process closer to the process of construction of scientific knowledge by providing them with experiences that, with due adaptation, reproduce the work carried out by scientists (Handlesmann et al., 2006; Hofstein & Lunetta, 2003).

Practical work continues to be a central and distinctive feature of science education and a vital element for its appeal and effectiveness (Abrahams & Millar 2008; Toplis, 2011). Understood as those activities which involve the manipulation of objects (Abrahams, 2011; Abrahams & Milar, 2009; Toplis, 2011), practical work is acknowledged as a valuable tool to promote learning at conceptual, procedural and attitudinal levels (Hodson, 2003; Rudduck, & McIntyre, 2007; Wellington, 2002). Particularly through its laboratory component, it is argued to immerse students in a motivating environment in which they are given the chance to investigate natural phenomena, pose questions and explain assertions based on evidence (Hofstein & Lunetta 2003). Practical activities have been shown to foster students' learning by: enhancing their interest (Abrahams, 2009; Rudduck & McIntyre, 2007); promoting peer interaction (Rudduck & McIntyre, 2007; Toplis, 2011); prompting improved scientific reasoning stemming from their experience with the investigative character of science (Abrahams, 2011); and enabling the connexion between observable phenomena or objects and students' ideas (Abrahams, 2011; Rudduck & McIntyre, 2007; Wellington, 2005). Therefore, in the case of biotechnology education, practical work has the potential to impact the constructs mentioned in the previous section: knowledge, attitudes and motivation.

In spite of the aforemntioned, the effectiveness of practical work has been questioned due to the lack of robust and reliable indicators of its educational outcomes (Abrahams, 2009; Abrahams & Millar, 2008; Millar, 1998; Psillos & Niedderer, 1999; Wellington, 1998). It has been argued that, given the diversity of activities that can be grouped under the common denominator that is "practical work", it is necessary to extend the range of studies on this topic by focusing on specific activities (Abrahams & Mikllar 2008; Holstermann, Grube, & Bögeholz, 2010). Regardless of this discussion, a weight of evidence about the educational worth of active learning supports the argument raised by currently advocated STSE and SSI curricula, that assuring the meaningfulness of the activities for the students is an essential requirement for its effectiveness (Hofstein & Lunetta, 2003; Kipnis & Hofstein, 2008; Rudduck & McIntyre, 2007; Toplis, 2011).

Biotechnology is reportedly a curricular topic that captures students' attention, about which they seem to be willing to know more about (Harms, 2002; Kidman, 2008, 2010). Apart from the debate about controversial issues, students appear to be particularly interested in practical activities that allow them to get acquainted with laboratory procedures involved in biotechnology (Kidman, 2010). Furthermore, the integration of inquiry-based learning in biotechnology education has shown to contribute to increased motivation, self-efficacy and knowledge (Hanegan & Bigler, 2010). Given the degree of abstractness of numerous biotechnology concepts, practical work can help to establish links between the observable and the conceptual domains.

Although the incorporation of inquiry-based practical work in science education is consistently recommended, studies suggest that these methodologies are not widely used in biotechnology education (Hanegan & Bigler, 2010; Steele & Aubusson, 2004). In 2004, Steele and Aubusson noticed that teachers identify an array of obstacles to the teaching of biotechnology through practical work, as for instance, the lack of activities suited for the contents to address, but also the lack of time to prepare and develop the activities and also the limited resources available (Steele & Aubusson, 2004). These observations were sustained by Kidman's work in 2010, in which the need for teachers to be open to learn new pedagogy and laboratory competencies is discussed (Kidman, 2010). Indeed, both biotechnology and inquiry-based practical work can be challenging for teachers, especially those who are uneasy with biotechnology issues and have limited experience and pedagogical content knowledge (Barnett & Hodson, 2001; Forbes & Davis, 2010; Gess-Newsome, 1999; Gray & Bryce, 2006; van Driel, Beijaard, & Verloop, 2011). If implemented lightly, for instance by dismissing oriented teacher training, the new approaches to scientific literacy, particularly inquiry based-learning, can often render teachers unable to engage in the development of teaching materials and methods essential to enact with the biotechnology curriculum (Lang, Drake, & Olson, 2006; Lee, Hart, Cuevas, & Enders, 2004; van Driel et al., 2001). Thus, when planning to develop practical activities to address biotechnology topics, all the above aspects must be accounted for, namely the students' and the teachers' features, needs and beliefs, the science curricula, and the implementation context.

Rationale and Purpose of this study

Studies conducted in different countries reveal that, in spite of the countless initiatives and resources to promote biotechnology, science curricula still hold weaknesses regarding the coverage of these topics, and both students and teachers remain reluctant to address basic biotechnology concepts, often displaying misconceptions, poor knowledge and negative attitudes towards biotechnology applications (Dawson, 2007; Dawson & Soames, 2006; Fitzsimmons, 2007; Prokop, et al., 2007; Sáez, et al., 2008; Steele & Aubusson, 2004). This emphasises the need to gather reliable indicators of the effectiveness of the initiatives that have been put forth. Thus far, the efficacy of the investment made in biotechnology education has been mainly evaluated by popularity, and less by specific and objective indicators, such as knowledge, interest, importance, and attitudes of the current students, i.e. the future decision-makers. With this in mind, the following questions can be raised:

- What are the students' and teachers' limitations and demands regarding biotechnology?
- How efficient are the resources available to promote biotechnology education?
- What are the learning outcomes of the resources available?
- What kind of assessment is being made?

With the purpose of unveiling the educational impact of resources for biotechnology education, the main goal of this project was to develop, implement and assess a selection of educational activities and resources to promote scientific literacy concerning biotechnology among elementary and high school students.

Objectives and Research questions

The success of any instructional strategy and the efficiency of a given educational activity depend on their adaptation to the features and needs of the target population and to the implementation context considered. When planning to implement an educational activity in a formal learning context, like the one students encounter in school, it is necessary to take into account the specificities of the teaching-learning process in what concerns the elements that modulate the interaction between students, teachers and the resource materials that mediate the contents to be addressed (Grubb & Cox, 2005; Siti Hendon & Khalijah, 2007) (Fig. I.3).

Therefore, a thorough characterisation of elementary and high school students' perceptions about biotechnology was required to comprehensively design or adapt the educational activities to be assessed. Regarding the teachers, they are unquestionably recognised as key agents not only in promoting the development of knowledge, but more importantly, in mediating the development of the student's potential of self-commitment in inquiry-based learning processes (Lee et al., 2004). The teacher's conduct is influenced by his/hers background as well as by the feedback from the interaction with the students, the contents and the educational contexts (Siti Hendon & Khalijah, 2007; van Driel et al., 2001). Furthermore, teachers can provide valuable feedback about limitations and constraints posed at their practice. Although some studies already exist on the topic, not much was known about what Portuguese science teachers think about biotechnology and biotechnology education and the constraints they face when addressing biotechnology in an educational context.

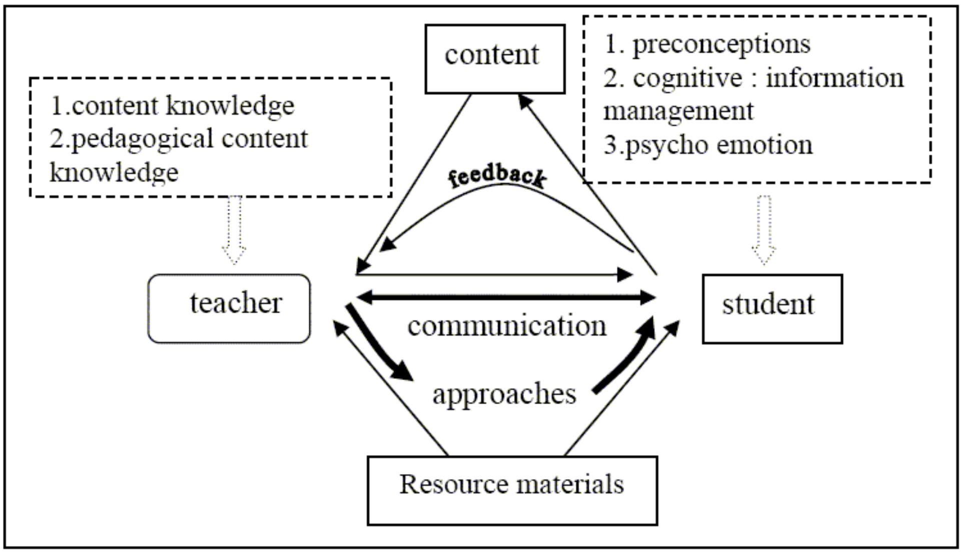

Fig. I.3. Schematic representation of the interaction between the main elements involved in the teaching-learning process (Siti Hendon & Khalijah, 2007).

Considering all the above aspects, two aims were defined:

i) Make the diagnostic of biotechnology education in Portugal, by gathering data about elementary and high school student's perceptions about biotechnology, and also their teachers' beliefs about biotechnology and biotechnology education;
ii) Develop a set of practical activities that suitably fit into school laboratory settings, and evaluate their potential to improve students' scientific literacy.

In line with these aims, the following research questions were formulated:

1. What do students know and think about biotechnology? How does the network of factors mediating students' perceptions about biotechnology operate? To what extent are these factors affected by the students' age, gender and academic profile?
2. How do biology teachers perceive biotechnology education? Which are the main factors affecting their activity?
3. Can students' understanding, motivation and attitudes towards biotechnology be improved through the use of inquiry-based experimental work?

Outline of the thesis

This thesis is organised in seven chapters, with the first chapter corresponding to a general introduction and the last chapter to a general discussion that features future perspectives. Chapters II to VI, presented in the form of articles, encompass the research carried out to address the research questions.

Chapter II focuses on the development and validation of the questionnaire used to assess students' perceptions about biotechnology. In addition to present the outcomes of the procedures related with the measurement instrument specifically used in this project, this chapter advances a set of oriented guidelines for the validation of quantitative data in other similar studies.

Chapter III details a multidimensional analysis of high school students' perceptions about biotechnology. More than providing a reliable characterisation of students' knowledge, attitudes, interest on biotechnology, and the importance they give to it, this chapter cross-examines and discusses the interaction between these dimensions.

Chapter IV depicts teachers' beliefs about biotechnology and biotechnology education. The outcomes of a comparative analysis of the influence that these endogenous elements have on teachers' practice, and the impact of exogenous elements that also affect teaching, namely the availability of materials and resources, and schedule requirements are discussed in this chapter.

Chapter V focuses on the development of a hands-on activity on antibiotic use and resistance which was implemented during the course of this project. The chapter also includes an activity developed following identical procedures, but focusing on the bactericidal effect of sunlight to illustrate how this type of activity can be extended beyond the scope of biotechnology to address other curricular topics of interest.

Chapter VI refers to the validation of the activity on antibiotic use and resistance in informal and formal education settings. The assessment of the effectiveness of this hands-on activity, as part of an informal educational project and as a classroom activity framed within the curriculum, are described and their outcomes discussed.

This thesis also includes as **Appendices**, the original versions of the interview scripts.

List of publications included in this thesis

Some of the outcomes of the research carried out during the course of the project that integrate this thesis have been conveyed in five papers published in international peer-reviewed journals and conference proceedings, in two manuscripts currently under review, and in a paper published in the proceedings of an international conference. Permission from the copyright holders was obtained to reproduce the papers originally published in international scientific journals that are presented. Since journals and other publications have specific and distinct graphical representation guidelines, the text, tables and figures of the articles presented herein have been standardised and formatted according to the style defined for the thesis, although their content is the same displayed in the original publications.

Publications in international peer reviewed journals:

Fonseca, M. J., Costa, P., Lencastre, L., & Tavares, F. (2012). Multidimensional analysis of high school students' perceptions about biotechnology. *Journal of Biological Education*, 46(3), 129-139. DOI: 10.1080/00219266.2011.634019 **(Chapter III, pp. 131-152)**

Fonseca, M. J., Costa, P., Lencastre, L., & Tavares, F. (2012). Disclosing biology teachers' beliefs about biotechnology and biotechnology education. *Teaching and Teacher Education, 28*(3), 368-381. DOI: 10.1016/j.tate.2011.11.007 **(Chapter IV, pp.153-204)**

Fonseca, M. J., & Tavares, F. (2011). Natural antibiotics: a hands-on activity on garlic's antibiotic properties. *American Biology Teacher*, *73*(6), 342-346. DOI: 10.1525/abt.2011.73.6.7 **(Chapter V, pp.207-217)**

Fonseca, M. J., & Tavares, F. (2011). The bactericidal effect of sunlight. *American Biology Teacher, 73*(9), 548-552. DOI: 0.1525/abt.2011.73.9.8 (**Chapter V, pp. 218-230**)

Fonseca, M. J., Santos, C. L., Costa, P., Lencastre, L., & Tavares, F. (2012). Increasing awareness about antibiotic use and resistance: a hands-on project for high school students. *PLoS ONE*, *7*(9), e44699. DOI: 10.1371/journal.pone.0044699 (**Chapter VI, pp. 231-268**)

Manuscripts under review:

Fonseca, M. J., Costa, P., Lencastre, L., & Tavares, F. (2012). A statistical approach to quantitative data validation focused on the assessment of students' perceptions about biotechnology (submitted). (**Chapter II, pp. 91-130**)

Fonseca, M. J., Santos, C. L., Costa, P., Lencastre, L., & Tavares, F. (2012). Practical work in high school: assessing its effectiveness through an empirical-based analysis. (submitted). (**Chapter VI, pp. 269-304**)

Publications in international conference proceedings:

Fonseca, M. J., Costa, P., Lencastre, L. & Tavares, F. (2009). Assessing assessment tools: towards questionnaire improvement through validation. In G. Cakmakci & M.F. Tasar (Eds.), *Contemporary science education research: learning and assessment* (pp. 259-266). Ankara, Turkey: Pegem Akademi. DOI: hdl.handle.net/10216/56221 (**Chapter II, pp. 77-90**)

Three additional papers, although not included in this thesis, have been written and published as research extensions to this PhD project:

Fonseca, M. J., Santos, C. L., & Tavares, F. (2012). A hands-on project to address antibiotic resistance in high school. Proceedings of the ESERA 2011 Conference, *Science learning and citizenship*. Lyon, France. http://lsg.ucy.ac.cy/esera/e_book/base/strand1.html

Fonseca, M. J., Franco, N. H., Brosseron, F., Tavares, F., Olsson, I. A. S., & Santos, J.B. (2011). Children's attitudes towards animals: evidence from the RODENTIA project. *Journal of Biological Education*, *45*(3), 121-128. DOI: 10.1080/00219266.2011.576259

Fonseca, M.J., Franco, N.H., Brosseron, F., Tavares, F., Olsson, I.A.S. & Santos, J.B. (2012). Children's attitudes towards animals: evidence from the RODENTIA project. In: A. Yarden & G.S. Carvalho (Eds.) *Authenticity in biology education: Benefits and challenges*. A selection of papers presented at the 8th Conference of European Researchers in Didactics of Biology (ERIDOB). Braga, Portugal. http://projectos.iec.uminho.pt/eridob/proceedings.html

References

Abd-El-Khalick, F., & Akerson, V. L. (2004). Learning as conceptual change: Factors mediating the development of preservice elementary teachers' views of nature of science. *Science Education, 88*(5), 785-810.

Abrahams, I. (2009). Does practical work really motivate? A study of the affective value of practical work in secondary school science. *International Journal of Science Education, 31*(17), 2335-2353.

Abrahams, I. (2011). Practical work in secondary science: a minds-on approach. London; New York: Continuum International Publishing Group.

Abrahams, I., & Millar, R. (2008). Does practical work really work? A study of the effectiveness of practical work as a teaching and learning method in school science. *International Journal of Science Education, 30*(14), 1945-1969.

Abrahams, I., & Millar R. (2009). Does practical work really motivate? A study of the affective value of practical work in secondary school science. *International Journal of Science Education*, *31*(7), 2335-2353.

Amin, L., Jahi, J. M., Nor, A. R. M., Osman, M., & Mahadi, N. M. (2007). Public Acceptance of Modern Biotechnology. *Asia Pacific Journal of Molecular Biology and Biotechnology, 15*(2), 39-51.

Auler, D., & Delizoicov, D. (2006). Ciência-Tecnologia-Sociedade: relações estabelecidas por professores de ciências. *Revista Electrónica de Enseñanza de las Ciencias, 5*(2), 337-355.

Barnett, J., & Hodson, D. (2001). Pedagogical context knowledge: Toward a fuller understanding of what good science teachers know, *Science Education, 85*(4), 426-453.

Bennett, J., Lubben, F., & Hogarth, S. (2007). Bringing science to life: A synthesis of the research evidence on the effects of context-based and STS approaches to science teaching. *Science Education, 91*(3), 347-370.

Beyer, P., Al-Babili, S., Ye, X., Lucca, P., Schaub, P., Welsch, R., & Potrykus, I. (2002). Golden rice: Introducing the β-carotene biosynthesis pathway into rice endosperm by genetic engineering to defeat vitamin A deficiency. *The Journal of Nutrition, 132*(3), 506S-510S.

Bock, R. (2007). Plastid biotechnology: prospects for herbicide and insect resistance, metabolic engineering and molecular farming. *Current Opinion in Biotechnology, 18*(2), 100-106.

Bonfadelli, H. (2005). Mass media and biotechnology: Knowledge gaps within and between European countries. *International Journal of Public Opinion Research, 17*(1), 42-62.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (Ed.). (2000). *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academy Press.

Braun, R., & Moses, V. (2004). A public policy on biotechnology education: what might be relevant and effective? *Current Opinion in Biotechnology, 15*(3), 246-249.

Brossard, D., & Nisbet, M. C. (2007). Deference to scientific authority among a low information public: Understanding U.S. opinion on agricultural biotechnology. *International Journal of Public Opinion Research, 19*(1), 24-52.

Bud, R. (1994). T*he uses of life: a history of biotechnology*. Cambridge: Cambridge University Press.

Bybee, R., & McCrae, B. (2011). Scientific literacy and student attitudes: Perspectives from PISA 2006 science. *International Journal of Science Education, 33*(1), 7-26.

Cabo Hernández, J. M., Enrique Mirón, C., & Cortiñas Jurado, J. R. (2006). Opiniones e intenciones del profesorado sobre la participación social en ciencia y tecnología. El caso de la biotecnologia. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias, 3*(3), 349-369.

Cachapuz, A. F., Praia, J. F., & Jorge, M. P. (2001). *Perspectivas de ensino. Textos de apoio nº1*. Porto: Centro de. Estudos de Educação em Ciência.

Cachapuz, A., Paiva, J., & Jorge, M. (2004). Da educação em ciência às orientações para o ensino das ciências: um repensar epistemológico. *Ciência & Educação*, *10*(3), 363-381.

Canavari, M., & Nayga, R. M. (2009). On consumers' willingness to purchase nutritionally enhanced genetically modified food. *Applied Economics, 41*(1), 125-137.

Cantley, M. (2004). How should public policy respond to the challenges of modern biotechnology? *Current Opinion in Biotechnology, 15*(3), 258-263.

Chen, S.-Y., & Raffan, J. (1999). Biotechnology: student's knowledge and attitudes in the UK and Taiwan. *Journal of Biological Education, 34*, 17-23.

Concannon, J., Siegel, M., Halverson, K., & Freyermuth, S. (2010). College students’ conceptions of stem cells, stem cell research, and cloning. *Journal of Science Education and Technology, 19*(2), 177-186.

Costa, M. J. (2007). Blackboard electrophoresis. *Biochemistry and Molecular Biology Education, 35*(5), 328-331.

Costa-Font, M., Gil, J. M., & Traill, W. B. (2008). Consumer acceptance, valuation of and attitudes towards genetically modified food: Review and implications for food policy. *Food Policy, 33*(2), 99-111.

Cuevas, P., Lee, O., Hart, J., & Deaktor, R. (2005). Improving science inquiry with elementary students of diverse backgrounds. *Journal of Research in Science Teaching, 42*(3), 337-357.

Dąbrowska, P. (2004). GM foods, risk, precaution and the internal market: Did both sides win the day in the recent judgment of the European court of justice? *German Law Journal, 5*(2), 151-166.

Davies, K. G., & Wolf-Phillips, J. (2006). Scientific citizenship and good governance: Implications for biotechnology. *Trends in Biotechnology, 24*(2), 57-61.

Dawson, V. (2007). An exploration of high school (12–17 year old) students' understandings of, and attitudes towards biotechnology processes. *Research in Science Education, 37*(1), 59-73.

Dawson, V., & Soames, C. (2006). The effect of biotechnology education on Australian high school students’ understandings and attitudes about biotechnology processes. *Research in Science & Technological Education, 24*(2), 183-198.

Dawson, V., & Venville, G. J. (2009). High-school students’ informal reasoning and argumentation about biotechnology: An indicator of scientific literacy? *International Journal of Science Education, 31*(11), 1421-1445.

Dawson, V. M., & Venville, G. (2010). Teaching strategies for developing students' argumentation skills about socioscientific issues in high school genetics. *Research in Science Education, 40*(2), 133-148.

Departamento da Educação Básica. (2001a). *Currículo nacional do ensino básico: Competências essenciais*. Lisboa: Ministério da Educação.

Departamento da Educação Básica. (2001b). *Orientações curriculares do ensino Básico - Ciências Físicas e Naturais.* Lisboa: Ministério da Educação.

Direcção-Geral de Inovação e de Desenvolvimento Curricular. (2004). *Programa de biologia 12º ano. curso científico-humanístico de ciências e tecnologias.* Lisboa: Ministério da Educação.

Einsiedel, E. F. (2005). Public perceptions of transgenic animals. *Revue Scientifique et Technique-Office International Des Epizooties*, *24*(1), 149-157.

Einsiedel, E. (2008). Public participation and dialogue. In M. Bucchi & B. Trench (Eds.), *Handbook of public communication of science and technologyi* (pp. 173-184). London; New York: Routledge.

Einsiedel, E., Premji, S., Geransar, R., Orton, N., Thavaratnam, T., & Bennett, L. (2009). Diversity in public views toward stem cell sources and policies. *Stem Cell Reviews and Reports, 5*(2), 102-107.

Elster, D. (2007). Student interests -- the German and Austrian ROSE survey. *Journal of Biological Education, 42*(1), 5-11.

European Comission (2002). *Science and society action plan*. Luxembourg: European Commission, Office for Official Publications.

Falk, H., Brill, G., & Yarden, A. (2008). Teaching a biotechnology curriculum based on adapted primary literature. *International Journal of Science Education, 30*(14), 1841-1866.

Finucane, M. L. (2002). Mad cows, mad corn and mad communities: the role of socio-cultural factors in the perceived risk of genetically-modified food. *Proceedings of the Nutrition Society, 61*(01), 31-37.

Fisher, H. E., & Mintz, C. S. (2000). Use of the green fluorescent protein as an educational tool. *Journal of Industrial Microbiology and Biotechnology, 24*(5), 323-326.

Fitzsimons, P. (2007). Biotechnology, ethics and education. *Studies in Philosophy and Education, 26*(1), 1-11.

Forbes, C. T., & Davis, E. A. (2010). Curriculum design for inquiry: Preservice elementary teachers' mobilization and adaptation of science curriculum materials. *Journal of Research in Science Teaching, 47*(7), 820-839.

France, B. (2003). GE Free: Rejection or Incomprehension? The Challenge for New Zealand biotechnologye. *Canadian Journal of Science, Mathematics and Technology Education, 3*(1), 145-156.

Frewer, L., Lassen, J., Kettlitz, B., Scholderer, J., Beekman, V., & Berdal, K. G. (2004). Societal aspects of genetically modified foods. *Food and Chemical Toxicology, 42*(7), 1181-1193.

Ganguli, P., Prickril, B., & Khanna, R. (2009). *Technology Transfer in Biotechnology: A Global Perspective*. Weinheim: John Wiley & Sons.

Gardner, G., Jones, G., Taylor, A., Forrester, J., & Robertson, L. (2010). Students' risk perceptions of nanotechnology applications: Implications for science education. *International Journal of Science Education, 32*(14), 1951-1969.

Gaskell, G., Allum, N., Bauer, M. W., Jackson, J., Howard, S., & Lindsey, N. (2003). *Ambivalent GM nation? Public attitudes to biotechnology in the UK, 1991-2002*. Life sciences in European society report: London School of Economics and Political Science.

Gaskell, G., Stares, S., Allansdottir, A., Allum, N., Corchero, C., Fischler, C., …Wagner, W. (2006). Europeans and biotechnology in 2005: Patterns and trends. Final report on Eurobarometer 64.3. Brussels: European Commission, Research Directorate-General.

Gaskell, G., Allansdottir, A., Allum, N., Castro, P., Esmer, Y., Fischler, C., …Wager, W. (2010). Europeans and Biotechnology in 2010. Winds of change? Brussels: European Commission Directorate-General for Research.

Gaskell, G., Allansdottir, A., Allum, N., Castro, P., Esmer, Y., Fischler, C., …Wager, W. (2011). The 2010 Eurobarometer on the life sciences. *Nature Biotechnology, 29*(2), 113-114.

Gess-Newsome, J. (1999). Secondary teachers' knowledge and beliefs about subject matter and their impact on instruction. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 51-94). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Gray, D. S., & Bryce, T. (2006). Socio-scientific issues in science education: Implications for the professional development of teachers. *Cambridge Journal of Education, 36*(2), 171-192.

Grimsrud, K. M., McCluskey, J. J., Loureiro, M. L., & Wahl, T. I. (2004). Consumer attitudes to genetically modified food in Norway. *Journal of Agricultural Economics, 55*(1), 75-90.

Grubb, W. N., & Cox, R., D. (2005). Pedagogical alignment and curricular consistency: The challenges for developmental education. *New Directions for Community Colleges, 2005*(129), 93-103.

Gutteling, J. M. (2005). Mazur's hypothesis on technology controversy and media. *International Journal of Public Opinion Research, 17*(1), 23-41.

Hamilton, K., Barfoot, J., Crawford, K. E., Simpson, C. G., Beaumont, P. C., & Bownes, M. (2006). Amplification of chloroplast DNA using the polymerase chain reaction (PCR): A practical activity for secondary school students. *Journal of Biological Education, 40*(4), 172-177.

Handelsman, J., Ebert-May, D., Beichner, R., Bruns, P., Chang, A., DeHaan, R., Gentile, J., Lauffer, S., Stewart, J., Tilghman, S. M., & Wood, W. B. (2004). Scientific teaching. *Science, 304*(5670), 521-522.

Handelsman, J., Miller, S., & Pfund, C. (2006). *Scientific teaching*. New York: W. H. Freeman.

Hanegan, N., & Bigler, A. (2009). Infusing authentic inquiry into biotechnology. *Journal of Science Education and Technology, 18*(5), 393-401.

Harms, U. (2002). Biotechnology education in schools. *Electronic Journal of Biotechnology, 5*(3), 205-211.

Helton, A. M., Zhao, J.-Z., & Roush, R. T. (2002). Economic, ecological, food safety, and social consequences of the deployment of Bt transgenic plants. *Annual Review of Entomology, 47*(1), 845-881.

Ho, S. S., Brossard, D., & Scheufele, D. A. (2008). Effects of value predispositions, mass media use, and knowledge on public attitudes toward embryonic stem cell research. *International Journal of Public Opinion Research, 20*(2), 171-192.

Hodson, D. (2003). Time for action: Science education for an alternative future. *International Journal of Science Education, 25*(6), 645-670.

Hofstein, A., & Lunetta, V. N. (2003). The laboratory in science education: foundations for the twenty-first century. *Science Education, 88*(1), 28-54.

Holbrook, J., & Rannikmae, M. (2007). The nature of science education for enhancing scientific literacy. *International Journal of Science Education, 29*(11), 1347-1362.

Holstermann, N., Grube, D., & Bögeholz, S. (2010). Hands-on activities and their influence on students' interest. *Research in Science Education, 40*(5), 743-757.

Hoover, E., Brown, P., Averick, M., Kane, A., & Hurt, R. (2009). Teaching small and thinking large: Effects of including social and ethical implications in an interdisciplinary nanotechnology course. *Journal of Nano Education, 1*(1), 86-95.

Huffman, W. E., Rousu, M., Shogren, J. F., & Tegene, A. (2004). Who do consumers trust for information: the case of genetically modified foods? *American Journal of Agricultural Economics, 86*, 1222-1229.

Jauhar, P. P. (2006). Modern biotechnology as an integral supplement to conventional plant breeding: The prospects and challenges. *Crop Science, 46*(5), 1841-1859.

Julien, H., & Barker, S. (2009). How high-school students find and evaluate scientific information: A basis for information literacy skills development. *Library & Information Science Research, 31*(1), 12-17.

Kamaldeen, S. & Powell, D. A. (2000). Public perceptions of biotechnology. Food Safety Network Technical Report #17, Department of Plant Agriculture, University of Guelph.

Kidman, G. (2008). Asking students: What key ideas would make classroom biology interesting? *Teaching Science, 54*(2), 34-38.

Kidman, G. (2010). What is an 'interesting curriculum' for biotechnology education? Students and teachers opposing views. *Research in Science Education, 40*(3), 353-373.

Kipnis, M., & Hofstein, A. (2008). The inquiry laboratory as a source for development of metacognitive skills. *International Journal of Science and Mathematics Education, 6*(3), 601-627.

Klerck, D., & Sweeney, J. C. (2007). The effect of knowledge types on consumer-perceived risk and adoption of genetically modified foods. *Psychology & Marketing, 24*(2), 171-193.

Klop, T., & Severiens, S. (2007). An exploration of attitudes towards modern biotechnology: A study among Dutch secondary school students. *International Journal of Science Education, 29*(5), 663 - 679.

Klop, T., Severiens, S. E., Knippels, M.-C. P. J., van Mil, M. H. W., & Ten Dam, G. T. M. (2010). Effects of a science education module on attitudes towards modern biotechnology of secondary school students. *International Journal of Science Education, 32*(9), 1127-1150.

Klosterman, M. L., & Sadler, T. D. (2010). Multi-level assessment of scientific content knowledge gains associated with socioscientific issues-based instruction. *International Journal of Science Education, 32*(8), 1017-1043.

Knight, A. (2007). Intervening effects of knowledge, morality, trust, and benefits on support for animal and plant biotechnology applications. *Risk Analysis, 27*, 1553-1563.

Kolstø, S. D. (2001). Scientific literacy for citizenship: Tools for dealing with the science dimension of controversial socioscientific issues. *Science Education, 85*(3), 291-310.

Lamanauskas, V., & Makarskaitė-Petkevičienė, R. (2008). Lithuanian university students' knowledge of biotechnology and their attitudes to the taught subject. *Eurasia Journal of Mathematics, Science & Technology Education, 4*(3), 269-277.

Lang, M., Drake, S., & Olson, J. (2006). Discourse and the new didactics of scientific literacy. *Journal of Curriculum Studies, 38*, 177-188.

Lee, O., Hart, J. E., Cuevas, P., & Enders, C. (2004). Professional development in inquiry-based science for elementary teachers of diverse student groups. *Journal of Research in Science Teaching, 41*(10), 1021-1043.

Lindahl, M. G. (2009). Ethics or morals: Understanding students' values related to genetic tests on humans. *Science & Education, 18*(10), 1285-1311.

Lindahl, M. G. (2010). Of Pigs and men: Understanding students' reasoning about the use of pigs as donors for xenotransplantation. *Science & Education, 19*(9), 867-894.

Longtin, S., Guilfoile, P., & Asper, A. (2004). Genotypic detection of antibiotic resistance in *Escherichia coli*: a classroom exercise. *Journal of Biological Education, 39*, 32-34.

Magnusson, M. K., & Hursti, U. K. K. (2002). Consumer attitudes towards genetically modified food. *Appetite, 39*, 9-24.

Malinowski, M. J., & Arnold, B. E. (1999). *Biotechnology: Law, business, and regulation*. Aspen: Aspen Publishers, Inc.

Matthews, M. R. (1998). *Constructivism in science education: A philosophical examination*. Dordrecht: Kluwer Academic.

McGloughlin, M. N. (2006). A retrospective prospective perspective on agricultural biotechnology ten years on. *Journal of Commercial Biotechnology, 13*(1), 20-27.

McGuire, W. J. (1969). The nature of attitudes and attitude change. In G. Lindzey & E. Aronson (Eds.), *The handbook of social psychology* (Vol. 3, pp. 133-314). Reading, MA: Addison-Wesley.

Michael, J. (2006). Where's the evidence that active learning works? *Advances in Physiological Education. 30*(4), 159-167.

Miles, S., Ueland, Oslash, Øydis, & Frewer, L. J. (2005). Public attitudes towards genetically-modified food. *British Food Journal, 107*, 246-262.

Millar, R. (1998). Rhetoric and reality. What practical work in science education is *really* for. In J. J. Wellington (Ed.), *Practical work in school science: which way now?* (pp. 16-31). London: Routledge.

Millar, R. (2006). Twenty first century science: insights from the design and implementation of a scientific literacy approach in school science. *International Journal of Science Education, 28*(13), 1499-1521.

Miller, H. I., & Conko, G. (2005). Agricultural Biotechnology: Overregulated and Underappreciated. *Issues in Science & Technology, 21*(2), 76-80.

Milne, C., & Morrison, A. (2007). Demystifying biotechnology: The PCR Game. *Teaching Science, 53*(1), 19-23.

Moerbeek, H., & Casimir, G. (2005). Gender differences in consumers' acceptance of genetically modified foods. *International Journal of Consumer Studies, 29*(4), 308-318.

Montgomery, R. (2003). Development of biobased products. *Applied Biochemistry and Biotechnology, 107*, 635-636.

Murphy, J., & Yanacopulos, H. (2005). Understanding governance and networks: EU–US interactions and the regulation of genetically modified organisms. *Geoforum, 36*, 593-606.

Nahum, L., Ben-Chaim, D., Azaiza, I., Herskovitz, O., & Zoller, U. (2010). Does STES-oriented science education promote 10th-grade students' decision-making capability? *International Journal of Science Education, 32*(10), 1315-1336.

Nisbet, M. C. (2004). Public *Opinion About Stem Cell Research and Human Cloning*. *Public Opinion Quarterly, 68*(1), 131-154.

Organization for Economic Co-operation and Development. (2006). *Evolution of student interest in science and technology studies policy report*. Paris: OECD.

Osborne, J., & Dillon, J. (2008). *Science education in Europe: critical reflections*. London: The Nuffield Foundation.

Pelletier, D. L. (2006). FDA's regulation of genetically engineered foods: Scientific, legal and political dimensions. *Food Policy, 31*(6), 570-591.

Petersen, A. (2005). The metaphors of risk: Biotechnology in the news. *Health, Risk & Society, 7*(3), 203-208.

Phillips, A. R., Robertson, A. L., Batzli, J., Harris, M., & Miller, S. (2008). Aligning goals, assessments, and activities: an approach to teaching PCR and gel electrophoresis. *CBE Life Sciences Education, 7*(1), 96-106.

Plunkett, J. W. (2012). *Plunkett's biotech & genetics industry almanac 2012: Biotech & genetics industry market research, statistics, trends & leading companies*. Houston, Texas: Plunkett Research, Ltd.

Praia, J., Gil-Pérez, D., & Vilches, A. (2007). O papel da natureza da ciência na educação para a cidadania. *Ciência e Educação, 13*(2), 141-156.

Prince, M. (2004) Does active learning work? A review of the research. *Journal of Engineering Education*, *93*(3), 223–231.

Prokop, P., Lesková, A., Kubiatko, M., & Diran, C. (2007). Slovakian Students' knowledge of and attitudes toward biotechnology. *International Journal of Science Education, 29*(7), 895-907.

Rheinberg, F., Vollmeyer, R., & Rollet, W. (2005). Motivation and action in self-regulation learning. In M. Boekaerts, P. Pintrich & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 503-530). Burlington, MA, San Diego, CA, London: Elsevier Science.

Rebello, C., Siegel, M., Witzig, S., Freyermuth, S., & McClure, B. (2012). Epistemic beliefs and conceptual understanding in biotechnology: a case study. *Research in Science Education, 42*(2), 353-371.

Psillos, D., & Niedderer, H. (1999). Issues and questions regarding the effectiveness of labwork. In D. Psillos & H. Niedderer (Eds.), *Teaching and learning in the science laboratory* (pp. 21-31). Dordrecht: Kluwer Academic Publishers.

Rittmann, B. E. (2006). Microbial ecology to manage processes in environmental biotechnology. *Trends in Biotechnology, 24*(6), 261-266.

Rosenberg, M. J., & Hovland, C. I. (1960). Cognitive, affective, and behavioral components of attitudes. In C. I. Hovland & M. J. Rosenberg (Eds.), *Attitude organization and change: An analysis of consistency among attitude components* (pp. 1-14). New Haven, CT: Yale University Press.

Rothhaar, R., Pittendrigh, B. R., & Orvis, K. S. (2006). The Lego analogy model for teaching gene sequencing and biotechnology. *Journal of Biological Education, 40*, 166-171.

Rudduck, J., & McIntyre, D. (2007). *Improving learning through consulting pupils*. New York: Routledge.

Ryan, R. M., & Deci, E. L. (2000). Intrinsic and extrinsic motivations: Classic definitions and new directions. *Contemporary Educational Psychology, 25*(1), 54-67.

Sadler, T. D., & Zeidler, D. L. (2004). The morality of socioscientific issues: Construal and resolution of genetic engineering dilemmas. *Science Education, 88*(1), 4-27.

Sáez, M. J., Niño, A. G., & Carretero, A. (2008). Matching society values: Students' views of biotechnology. *International Journal of Science Education, 30*(2), 167-183.

Sagar, A., Daemmrich, A., & Ashiya, M. (2000). The tragedy of the commoners: biotechnology and its publics. *Nature Biotechnology, 18*(1), 2-4.

Saini, B. L. (2010). *Introduction to biotechnology*. New Delhi: Laxmi Publications Pvt Ltd.

Sandoval, W. A. (2005). Understanding students' practical epistemologies and their influence on learning through inquiry. *Science Education, 89*(4), 634-656.

Santucci, A., Mini, R., Ferro, E., Martelli, P., & and Trabalzini, L. (2004). Innovative tools for scientific and technological education in Italian secondary schools. *Biochemistry and Molecular Biology Education, 32*(2), 78-83.

Savadori, L., Savio, S., Nicotra, E., Rumiati, R., Finucane, M., & Slovic, P. (2004). Expert and public perception of risk from biotechnology. *Risk Analysis, 24*, 1289-1299.

Scheitle, C. P. (2005). In God we trust: Religion and optimism toward biotechnology. *Social Science Quarterly, 86*, 846-856.

Scott, P., Asoko, H., & Leach, J. (2007). Student conceptions and conceptual learning in science. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of Research on Science Education* (pp. 31-56). Mahwah, NJ: Lawrence Erlbaum Associates

Scully, J. (2003). Genetic engineering and perceived levels of risk. *British Food Journal, 105*, 59-77.

Sjøberg, S., & Schreiner, C. (2006). How do students perceive science and technology? *Science in School,* 1, 66-69.

Schüler, J. (2006). Industrial application (biotech industry, markets and opportunities). In M. Wink (Ed.), *An introduction to molecular biotechnology: Molecular fundamentals, methods and applications in modern biotechnology* (615-630). Heildelberg: Wiley-VCH.

Shepherd, R., Barnett, J., Cooper, H., Coyle, A., Moran-Ellis, J., Senior, V. a., & Walton, C. (2007). Towards an understanding of British public attitudes concerning human cloning. *Social Science & Medicine, 65*(2), 377-392.

Shmaefsky, B. (2006). *Biotechnology 101*. Westport, CT: Greenwood Press.

Siegrist, M. (2000). The influence of trust and perceptions of risks and benefits on the acceptance of gene technology. *Risk Analysis, 20*(2), 195-204.

Siti Hendon, S. A., & Khalijah, M. S. (2007). Science teaching for enlightment: a holistic approach in developing a teachers' guide for best practices to teach at secondary level. *Asia-Pacific Forum on Science Learning and Teaching, 8*(1).

Steele, F., & Aubusson, P. (2004). The challenge in teaching biotechnology. *Research in Science Education, 34*, 365-387.

Sturgis, P., Cooper, H., & Fife-schaw, C. (2005). Attitudes to biotechnology: Estimating the opinions of a better-informed public. *New Genetics & Society, 24*(1), 31-56.

The Gallup Organization. (2009). *Young people and science*. Analytical report. Flash Eurobarometer No. 239. Brussels: European Commission, Research Directorate-General.

Todt, O. (2004). Regulating agricultural biotechnology under uncertainty. *Safety Science, 42*(2), 143-158.

Toplis, R. (2012). Students' views about secondary school science lessons: The role of practical work. *Research in Science Education, 42*(3), 531-549.

Uşak, M., Erdogan, M., Prokop, P., & Özel, M. (2009). High school and university students' knowledge and attitudes regarding biotechnology. *Biochemistry and Molecular Biology Education, 37*(2), 123-130.

Van Driel, J. H., Beijaard, D., & Verloop, N. (2001). Professional development and reform in science education: The role of teachers' practical knowledge. *Journal of Research in Science Teaching, 38*(2), 137-158.

Van Eijck, M. (2010). Addressing the dynamics of science in curricular reform for scientific literacy: The case of genomics. *International Journal of Science Education*, *32*(18), 2429-2449.

van Mil, M. H., Boerwinkel, D. J., Buizer-Voskamp, J. E., Speksnijder, A., & Waarlo, A. J. (2010). Genomics education in practice: Evaluation of a mobile lab design. *Biochemistry and Molecular Biology Education, 38*(4), 224-229.

Verdume, A., & Viaene, J. (2003). Exploring and modelling consumer attitudes towards genetically modified food. *Qualitative Market Research: An International Journal, 6*(2), 95-110.

Ward, H., & Hockey, J. (2007). Engaging the learner: Embedding information literacy skills into a biotechnology degree. *Biochemistry and Molecular Biology Education, 35*(5), 374-380. doi: 10.1002/bmb.79

Weber, K., & Custer, R. (2005). Gender based preferences toward technology education content, activities and instructional methods. *Journal of Technology Education, 16*(2), 55-71.

Wellington, J. J. (1998). *Practical work in school science: which way now?* London: Routledge.

Wellington, J. (2002). *Science learning, science teaching*. London: Taylor and Francis.

Wellington, J. (2005). Practical work and the affective domain: What do we know, what should we ask, and what is worth exploring further? In S. Aslop (Ed.), *Beyond cartesian dualism. encountering affect in the teaching and learning science* (pp. 99-110). Dordrecht: Springer.

Zeidler, D. L., Sadler, T. D., Applebaum, S., & Callahan, B. E. (2009). Advancing reflective judgment through Socioscientific Issues. *Journal of Research in Science Teaching, 46*(1), 74-101.

Zeidler, D. L., Sadler, T. D., Simmons, M. L., & Howes, E. V. (2005). Beyond STS: A research-based framework for socioscientific issues education. *Science Education, 89*(3), 357-377.

Zeidler, D. L., Walker, K. A., Ackett, W. A., & Simmons, M. L. (2002). Tangled up in views: Beliefs in the nature of science and responses to socioscientific dilemmas. *Science Education, 86*(3), 343-367.

CHAPTER II

Development and validation of a measurement instrument to assess elementary and high school students' perceptions about biotechnology

Subchapter 1

Assessing assessment tools: towards questionnaire improvement through validation

Fonseca, M. J., Costa, P., Lencastre, L., & Tavares, F.
G. Cakmaci & M.F. Tasar (Ed.s), *Contemporary science education research: learning and assessment* 2010
(pp. 259-266)
Ankara, Turkey: Pegem Akademi

Subchapter 2

A statistical approach to quantitative data validation focused on the assessment of students' perceptions about biotechnology

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Chapter II

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Subchapter 1

Assessing assessment tools: towards questionnaire improvement through validation

Abstract

A major concern of science education researchers has been to assess the effectiveness of educational strategies, namely curricular structure, alternative teaching approaches and informal learning environments. In these studies, parameters such as knowledge, attitudes and behaviours are frequently addressed using diverse instruments chosen to answer precise research questions. In order to adopt corrective measures it is fundamental to obtain reliable results. If case-study approaches can be suitable to study in detail specific teaching activities, they hardly give a wider view of the students' universe. In contrast, questionnaires are commonly used assessment tools that allow broad surveys of multiple aspects among a vast universe of students. Furthermore, they provide considerable amounts of easily treatable information in relatively short periods of time. For these reasons, educational observatories, as the well-known EUROBAROMETER, tend to favour inquiry-based assessment. Regardless of their apparent simplicity, questionnaire-based instruments require proper procedures to provide reliable and valid data. To comprehensively assess the knowledge, interest and attitudes of elementary and high school students from Porto towards biotechnology, and identify the sources they use and trust to gather information about it, an oriented questionnaire validation guideline is proposed, combining pilot work with statistical validation through exploratory factor scrutiny and reliability analysis.

Introduction

The ultimate goal of science education is the promotion of scientific literacy (Braun & Moses, 2004; Cabo Hernandez, Mirón, & Cortiñas Jurado, 2006), which is essential to assure that knowledgeable citizens are competent to take part in the democratic decision-making policies regarding scientific and technological processes. Biotechnology is one of the most controversial socio-scientific issues to date (Dawson, 2007; Klop & Severiens, 2007). Acknowledging the range and intensity of its impact on society, many studies have been conducted addressing public knowledge and attitudes towards biotechnology (Pin & Gutteling, 2009). However, the ones targeting student populations are still scarce (Dawson & Soames, 2006; Dawson, 2007; Firmino, 2007; Klop & Severiens, 2007; Prokop, Lešková, Kubitako, & Diran, 2007; Sáez, Niño, & Carretero, 2008, Uşak, Erdogan, Prokop, & Özel, 2009).

Quantitative inquiry surveys are the most suitable methodologies to achieve a broad characterisation of a given population, especially when planning to establish correlations and make generalisations (Oppenheim, 1992, Black 1999). Nevertheless, questionnaires have limitations that are mainly related to their subjectivity (Black, 1999). Thus, it is necessary to design and administer these instruments following proper procedures that can assure the validity and reliability of the results they provide (Brace, 2008). Although validation should be an intrinsic element of large scale assessment, many studies fail to report these procedures (Petrić & Cźarl, 2003). The decision to dismiss questionnaire validation may result from the perception that these statistical methods are not efficient given the time and effort they require, particularly since most research designs have strict timings (Dörnyei, 2002).

In this context, we designed a questionnaire to make the diagnostic of the knowledge, attitudes and decision-making capacity regarding biotechnology of elementary and high school students engaged in two different curricular formats: with and without biology contents. The consistency of this questionnaire was improved through a pilot study and using statistical approaches to increase the data's reliability. Exploratory factor analysis (EFA) and reliability analysis were conducted and their outcomes discussed.

Rationale

Questionnaire validation through a pilot study allows to identify, understand and address ambiguities that can interfere with the students' answers and compromise the reliability of the data gathered (Black, 1999; Oppenheim, 1992). It is important to assess the adequacy of the questionnaire's wording, length, structure and intelligibility, as well as the quality of the item's formulation, the scaling and the items' and questions' sequence (Black, 1999). The analysis of psychometric properties of the pilot study's data concerning the instrument is essential (Fabrigar, Wegener, MacCallum, & Strahan, 1999). Only then is the instrument ready to be administered.

Method

Participants

The questionnaire was applied in a representative sample of 92 students from three schools of Porto metropolitan area. Sample representativeness was assured by random selection of the participant schools. This sample comprised 46 students from two elementary 9^{th} grade classes and 46 high school students attending the 12^{th} grade. 25 of these 12^{th} graders were attending biology and the other 21 were engaged in curricular formats that do not include biology, namely economics, informatics, humanistic, and arts/design areas. Students from the 9^{th} and 12^{th} grades were chosen to participate in this study for two reasons. Firstly, these are the curricular years where more emphasis is given to biotechnology-related issues, according to the orientations of the Portuguese Ministry of Education (DEB, 2001; DGIDC, 2004). Secondly, since these are the concluding years of elementary and high school, many of these students end their academic training without any other formal contact with biotechnology.

Measurement instrument

The questionnaire's pilot version was conceived considering instruments previously described (Cabo Hernandez et al*.,* 2006; Dawson, 2007; Dawson & Soames, 2006; Firmino, 2007; Gaskell et al., 2006; Miles, Ueland, & Frewer*,* 2003; Prokop et al., 2007) and adapting relevant features to the Portuguese educational context. In addition, to better characterize the sample used and to increase the internal consistency of the instrument, new items were formulated. The questionnaire content was decided and assessed upon curricula and textbook analysis, thus assuring its validity. The pilot version consisted in a set of closed and semi-open questions, aiming to provide insights about the knowledge, attitudes, students' interest towards biotechnology and key sources of information used and trusted. Different scales were developed to assess each of these dimensions. The questions' wording, especially when translation was required, was carefully considered and the written language was adjusted to the characteristics of the respondents (Oppenheim, 1992). Negative phrasing was avoided and the items were formulated as objectively as possible to minimize bias (Black, 1999).

The questionnaire proposed consists in 14 questions, originally with a total of 65 items organised into 6 groups: *knowledge* (3 questions, 17 items), *attitudes* (2 questions, 18 items), *interest* (2 questions, 4 items), *comprehension of news about biotechnology* (1 question, 1 item), *sources of information about biotechnology used and trusted* (2 questions, 15 items) and *risk and benefit perception* (3 questions, 10 items). Despite its association with knowledge, the comprehension of news about biotechnology depends on how the information is divulged and therefore this item was isolated in its own category. The risk and benefit perception group comprises questions addressing behavioural intent regarding ethical and controversial issues, to assess the students' decision making capacity. Five factual data questions and one question concerning whether the students found the questionnaire interesting were added to better characterise the population and to enquire the receptivity towards this kind of approach, respectively. Five point Likert type scales were developed for each question, except for the questions in the *knowledge* section, that consists in a multiple choice question, a list of options and a True/ False/ Don't know question, and one question aimed at determining *sources of information used*, that presents a list of options to choose from. A *don't know* option was included in the True or False question to minimize social desirability bias (Black, 1999; Brace, 2008), and to assess the truthfulness of the students' answers.

Procedure

Data collection

The questionnaires were administered over a three month period, from October to December 2008, during class periods, without imposing time constraints, under the supervision of a teacher and/or the investigator. The time students took to complete the questionnaire was registered. Students were instructed to ask any questions resulting from difficulties in interpreting the questionnaire and regarding any words or concepts that might be unclear to them.

Data analysis

The data collected throughout the pilot study was codified according to a previously defined guideline, recorded and cleansed using the Statistical Package for the Social Sciences (SPSS) software version 17.0. After descriptive and missing values analysis of all the items in the questionnaire, the ones assessed by Likert type scales were subjected to EFA (principal component analysis [PCA] with varimax rotation) within their given dimension. Subsequently, by determining the Cronbach's alpha value for each factor identified, a reliability analysis was performed. The number of factors to retain following factor analysis was decided according to the Kaiser criterion (eigenvalues greater than 1) and the scree test (Costello & Osborne, 2005; Hayton, Allen, & Scarpello 2004). Items loading below 0.40, displaying low communality (below 0.40), cross-loading, freestanding or decreasing the scale's internal consistency were excluded from the analysis (Costello & Osborne, 2005; Fabrigar et al., 1999; Hogarty, Hynes, Kromrey, Ferron, & Mumford., 2005; Sharma, 1996). By comprehensively introducing some modifications in the pilot version, the final version of the questionnaire was obtained. It is worth to mention that although the items in the *knowledge* section and in the question regarding *sources of information used* were not subjected to factor analysis, both categories are included in the final version of the questionnaire. Item retention for these categories was based on the analysis of missing and ambiguous answers and on the results obtained for the scales subjected to factor analysis.

Results and Discussion

During the pilot study students did not identify major constraints that could justify any modifications regarding the content and structure of the questionnaire. Although there were three complaints about its length, all the students took less than 20 minutes to complete the whole set of questions. The maximum of missing values per item registered for the pilot sample (*n*=92) was 4.3%, so all the items were considered for subsequent analysis. The missing values were imputed using the series mean method in SPSS, given they were very limited and random (Batista & Monard, 2003; Huisman, 2000; Paul, Mason, McCaffrey, & Fox, 2008).

Factor analysis results, such as the ones summarised in Table II.1, led to the introduction of some changes in the questionnaire's structure, and justified the need to be aware of aspects that influence the interpretation of the data gathered. The total number of items in the questionnaire was reduced by eliminating three items that appeared to be redundant: (i) *Genetically modified organisms can endanger the environment (answer True/False/Don't Know)* (ii) *Rate your agreement towards the following sentence - the ingestion of genetically modified foods has adverse effects on humans (1-I totally disagree to 5-I totally agree)*; and (iii) *Rate your interest in participating in information campaigns about genetically modified organisms (1-I am not interested at all to 5-I am very interested)*. It also became evident that a rearrangement of the items was necessary. The *attitudes* and the *risk and benefit perception* sections of the pilot version of the questionnaire were combined and their items re-structured according to the tri-partite model of attitudes (Klop & Severiens, 2007), in a section intended to assess the cognitive, affective and behavioural components of attitudes. Additionally, two items, one from each of these two initial sections, were combined into a new category, which factor analysis showed to be consistent with only one factor: *importance of biotechnology to the quality of life*. The sample's adequacy to factor analysis was confirmed by the Kaiser-Meyer-Olkin (KMO) test results, except for the scales addressing the affective component of students' attitudes and the importance they give to biotechnology (KMO≤0.50). For these scales there seems to be a disperse pattern of correlations among variables, suggesting that a larger sample may yield better results (Sharma, 1996). Nevertheless, for each scale there is a significant (p<0.05) correlation between the variables tested, as it was demonstrated by the Bartlett's Test of Sphericity. Hence, it was decided to keep the factor structures identified for these scales throughout the main study to assess the effect of the sample's size on its adequacy. The best factor structures identified by factor analysis for *attitude's cognitive component* and t*rust in sources of information*, exclude many of the items initially proposed for those scales (Table II.2). However, failing to analyse such items would result in an important loss of information. Therefore, to improve the characterisation of the student population, it was decided to include those items along with the factors identified for each scale in the final version of the questionnaire (Table II.2).

From the reliability analysis carried out (Table II.1), not all the Cronbach's alpha values obtained are sufficiently robust, scoring below 0.60 (Hair, Anderson, Tatham, & Black, 1998; Wasserman & Bracket, 2003), which may be due to the low number of items for the factors considered (Costello & Osborne, 2005). Although the number of items could be increased, the characteristics of the target population and the feedback obtained during the pilot study rendered a longer questionnaire inappropriate (Dörnyei, 2002; Oppenheim, 1992). At this point, it may be expected that the tendencies observed would be strengthened by increasing the sample size during the final study.

EFA is an approach that requires many decisions and can produce misleading results (Fabrigar et al., 1999). Therefore, it is necessary to acknowledge that there are many factors affecting its outcomes, such as the design of the study, its aims and the data's properties (Costello & Osborne, 2005). In this study, our goal was to produce an adjusted instrument that can allow to reliably characterise the studied student population. Despite acknowledging that additional iterations would be beneficial to improve the consistency of the questionnaire's factor structures, it was decided to use the instrument in its current form during the main study. The validation process described proved to be of the utmost importance to emphasise aspects that were not obvious in the study's design.

Table II.1.

Scales' factor structure based on exploratory factor analysis (principal component analysis with varimax rotation) and reliability analysis.

Coefficients below 0.30 were suppressed.

Scale	Factor Analysis							Reliability Analysis
	KMO	Identifiable factor	EV	% variance	Item	Communality	Item loading	Cronbach's alpha
Attitudes' Cognitive component	0.57	*Classical applications*	1.19	14.88	- *Use of yeast in the production of bread. wine and beer*	0.69	0.80	0.64
					- *Use of yeast in animal food production*	0.76	0.87	
		Agro-food applications	1.51	18.84	- *Improvement of the growth of plant in saline environments by altering their genes*	0.71	0.83	0.62
					- *Production of pesticide resistant plants by gene manipulation*	0.64	0.67	
					- *Genetic modification of tomatoes to make them ripen more slowly and have a longer shelf life*	0.53	0.62	
		Bio-medical applications	2.52	31.47	- *Utilisation of genetically modified cows for the production of medicines for human*	0.71	0.82	0.67
					- *Use of insulin produced by bacteria*	0.59	0.73	
					- *Organ transplant from transgenic animals to humans*	0.58	0.72	
Attitudes' Affective component	0.449	*Embryonic cell utilization*	1.31	32.83	- *It is our duty to authorise investigation that may lead to the development of more efficient medical treatments. even if it implies using embryonic stem cells*	0.77	0.88	0.37
					- *It is wrong to use embryonic stem cells in biomedical research. even if it may contribute to the development of medical treatments*	0.69	0.49	
		Control capacity	1.17	29.27	- *The labels of transgenic food should specify whether the food or any of its ingredients is genetically modified*	0.62	0.66	0.33
					- *Each of us is capable of determining our intake of transgenic foods*	0.40	0.64	
Attitudes' Behavioural component	0.62	*Buying intent*	2.38	36.62	- *Buy transgenic foods if they were available in supermarkets*	0.72	0.85	0.63
					- *Buy medicines obtained by genetically manipulation*	0.42	0.62	
					- *Buy transgenic foods if they were healthier than other foods*	0.40	0.53	
					- *Buy transgenic foods if they were less expensive than other foods*	0.45	0.66	
		Access to genetic information	1.12	18.64	- *Do a genetic test for medical diagnostic*	0.81	0.89	0.69
					- *Give the police access to your genetic information*	0.70	0.81	
Interest	0.67	*Interest*	2.38	59.37	- *Rate your interest towards biotechnology*	0.37	0.61	0.77
					- *Listen to news about biotechnology*	0.58	0.76	
					- *Read articles or watch TV shows about biotechnology*	0.82	0.91	
					- *Search the web for subjects related to biotechnology*	0.61	0.78	
Trust in sources of information	0.661	*Industry*	2.11	42.11	- *Pharmaceutical industry*	0.61	0.77	0.63
					- *Agro-food industry*	0.67	0.82	
					- *Health industry*	0.58	0.71	
		NGO's	1.21	24.19	- *Environmental organizations*	0.74	0.86	0.67
					- *Consumer rights organizations*	0.71	0.82	
Importance	0.500	*Importance*	1.40	69.74	- *How important do you think biotechnology is to the quality of life?*	0.70	0.84	0.56
					- *Do you agree that future generations will benefit from biotechnology's medical applications?*	0.70	0.84	

KMO – Kaiser-Meyer-Olkin measure of sampling adequacy. EV – Eigenvalue.

Table II.2.

Questionnaire structure following validation

The factor structure identified for each scale is highlighted in bold.

SECTION / SCALE	EXAMPLE OF QUESTIONS USED
Factual questions	School you are attending; Grade you are attending; Age; Sex; Course you are attending
Knowledge assessment	Q1: Biotechnology can be defined as a set of processes… (Select the option you most agree with) (i)… in which recombinant DNA technology is used; (ii)… applied to investigation and product development; (iii)… which involves cell and tissue culture; (iv)… by which genetically modified organisms (GMOs) can be developed. Q2: From the biotechnological applications listed. select the one(s) you know. Production of medicines and vaccines; Production of hormones; Production of organic products. such as milk or yogurt; Recovery of contaminated soils using genetically modified bacteria; Waste treatment; Production of insect and pesticide resistant plants; Utilisation of plants with industrial purposes. namely the production of cosmetics. plastics and fuels; Production of amminoacids and vitamins. Q3: Answer the following questions using True/False/I don't know. The ingestion of genetically modified foods can induce gene alterations; Cloning and genetic engineering are identical processes; It is impossible to transfer genes from plants to animals; Genetically modified organisms contain dangerous chemicals; …
Importance assessment	Q4: **How important do you think biotechnology is to the quality of life? (1-Not at all important to 5-Very important)[a]** Q6c: **Rate your agreement with the following sentence (1-I disagree completely to 5-I agree completely): Do you agree that future generations will benefit from biotechnology's medical applications?[a]**
Attitudes assessment – cognitive component	Q5: Rate your approval towards the following activities (1-I do not approve it at all to 5-I approve it completely). **Use of yeast in the production of bread. wine and beer[b]**; **Use of yeast in animal food production[b]**; Use of genetically modified organisms in waste treatment; **Improvement of the growth of plant in saline environments by altering their genes[c]**; Treatment of genetic disorders by embryonic gene manipulation; Treatment of genetic disorders by human gene manipulation; Insertion of plant genes into animals; **Utilisation of genetically modified cows for the production of medicines for humans[d]; Production of pesticide resistant plants by gene manipulation[c]; Genetic modification of tomatoes to make them ripen more slowly and have a longer shelf life[c]; Use of insulin produced by bacteria[d]; Organ transplant from transgenic animals to humans[d]**; Medical treatments through human cloning.
Attitudes assessment – affective component	Q6: Rate your agreement with the following sentences (1-I totally disagree to 5-I totally agree). **It is our duty to authorise investigation that may lead to the development of more efficient medical treatments. even if it implies using embryonic stem cells[e]; The labels of transgenic food should specify weather the food or any of its ingredients is genetically modified[f]; It is wrong to use embryonic stem cells in biomedical research. even if it may contribute to the development of medical treatments[e]; Each of us is capable of determining our intake of transgenic foods[f]**.
Attitudes assessment – behavioural component	Q7: How often would you… (1-Never to 5-Always) **Buy transgenic foods if they were available in supermarkets[g]; Buy medicines obtained by genetically manipulation[g]**. Q13: How often would you… (1-Never to 5-Always) **Do a genetic test for medical diagnostic[h]; Give the police access to your genetic information[h]; Buy transgenic foods if they were healthier than other foods[g]; Buy transgenic foods if they were less expensive than other foods[g]**.
Interest assessment	Q8: **Rate your interest towards biotechnology (1-I am not interested at all to 5-I am very interested)[i]**. Q9: How often do you… (1-Never to 5-Many times) …**listen to news about biotechnology[i]**; …**read articles or watch TV shows about technology[i]**; …**search the web for subjects related to biotechnology[i]**.
Comprehension of news assessment	Q10: Rate your difficulty in understanding news about biotechnology (1-very low to 5-Very high).
Assessment of sources of information used	Q11: From which of the following sources do you most commonly obtain information about biotechnology? TV; Radio; Newspapers. Magazines; Scientific magazines; Internet; Textbooks; Teachers; Friends; Family; Others.
Assessment of trust in sources of information	Q12: Rate your trust in the following sources of information about biotechnology (1-I do not trust it/them at all to 5-I trust it/them completely): Media; Scientific magazines; **Pharmaceutical industry[j]**; **Agro-food industry[j]**; **Health industry[j]**; Governmental agencies; Universities; Scientists; Internet; **Environmental organisations[k]**; **Consumer rights organisations[k]**; European Community; Medical doctors; Politicians.

Items identified with the same letter (a, b, c, d, e, f, g, h, I, j, k) contribute to the same factor.

Conclusions and Implications

We believe that the quality of the data gathered through an inquiry-based methodology can be improved by an adequate validation of the instruments used. In addition, this procedure may be fundamental to assess and optimize the reliability and validity of those instruments and the results they provide. When developing new questionnaires, analysis of psychometric features can help reduce bias introduced by the author's own expectations towards the students' answers. Furthermore, it can unveil intrinsic and unpredicted conditioning factors. Validation also becomes crucial when planning to use already existent instruments, since the population to be assessed presumably differs from the ones for which those instruments were originally intended.

Overall, the work carried out underlines a guideline to similar diagnostic studies. A validation strategy was tested and its outcomes discussed, demonstrating that the investment in these time consuming procedures can improve the quality of the data gathered through quantitative assessment methodologies.

Acknowledgements

The authors are grateful to all the participant students and teachers and to Catarina L. Santos for helpful comments and suggestions on the manuscript. Maria João Fonseca is supported by the FCT fellowship SFRH/BD/37389/2007.

References

Batista, G., & Monard, M. (2003). An analysis of four missing data treatment methods for supervised learning. *Applied Artificial Intelligence*, 17(5), 519-533.

Black, T. R. (1999). *Doing quantitative research in the Social Sciences. An integrated approach to research design, measurement and statistics*. London: SAGE Publications.

Brace, I. (2008). *Questionnaire Design*. *How to Plan, Structure and Write Survey Material for Effective Market Research.* London: Kogan Page Publishers.

Braun, R., & Moses, V. (2004). A public policy on biotechnology education: what might be relevant and effective? *Current Opinion in Biotechnology*, *15(3)*, 246-249.

Cabo Hernández, J. M., Mirón, E., & Cortiñas Jurado, J. R. (2006). Opiniones e intenciones del professorado sobre la participación social en ciencia y tecnologia. El caso de la biotecnologia. *Revista Eureka Enseñanza e Divulgación de Ciencia*, *3*(3), 349-369.

Costello, A. B., & Osborne, J. W. (2005). Best practices in exploratory factor analysis: four recommendations for getting the most from your analysis. *Practical Assessment, Research and Evaluation*, *10*(7). Retrieved from http://pareonline.net/getvn.asp?v=10&n=7

Dawson, V. (2007). An Exploration of high school (12-17 year old) students' understandings of, and attitudes towards biotechnology processes. *Research in Science Education*, *37*(1), 59-73.

Dawson, V., & Soames, C. (2006). The effect of biotechnology education on Australian high school student's understandings and attitudes about biotechnological processes. *Research in Science and Technological Education*, *24*(2), 183-198.

Departamento da Educação Básica. (2001). *Orientações curriculares do ensino básico - ciências físicas e naturais*. Lisboa, Portugal: Ministério da Educação.

Direcção-Geral de Inovação e de Desenvolvimento Curricular. (2004). *Programa de biologia 12º ano. curso científico-humanístico de ciências e tecnologias*. Lisboa, Portugal: Ministério da Educação.

Dörnyei, Z. (2002). *Questionnaires in second language research: Construction, administration, and processing*. New Jersey: Lawrence Erlbaum Associates.

Fabrigar, L. R., Wegener, D. T., MacCallum, R. C., & Strahan, E. J. (1999). Evaluating the use of exploratory factor analysis in psychological research. *Psychological Methods*, *4*(3), 272-299.

Firmino, M. (2007). Biotecnologia – estudo exploratório das percepções e atitudes de professores e alunos. (Masters dissertation, Faculdade de Ciências, Universidade do Porto).

Gaskell, G., Stares, S., Allansdottir, A., Allum, N., Corchero, C., Fischler, C., ...Wagner, W. (2006). *Europeans and biotechnology in 2005: Patterns and trends. Final report on Eurobarometer 64.3.* Brussels: European Commission's Directorate-General for Research.

Hair, J. F., Anderson, R. E., Tatham, R. L., & Black, W. C. (1998). *Multivariate data analysis.* (5th ed.). New Jersey: Prentice-Hall.

Hayton, J. C., Allen, D. G., & Scarpello, V. (2004). Factor retention decisions in exploratory factor analysis: a tutorial on parallel analysis. *Organizational Research Methods*, *7*(2), 191-205.

Hogarty, K. Y., Hynes, C. V., Kromrey, J. D., Ferron, J. M., & Mumford, K. R. (2005). The quality of factor solutions in exploratory factor analysis: the influence of sample size, communality and overdetermination. *Educational and Psychological Measurement*, *65*(2), 202-226.

Huisman, M. (2000). Imputation of missing item responses: some simple techniques. *Quality and Quantity*, *34*(4), 331-251.

Klop, T., & Severiens, S. (2007). An exploratory of attitudes towards modern biotechnology: a study among Dutch secondary school students. *International Journal of Science Education*, **29**(5), 663-979.

Miles, S., Ueland, Ø., & Frewer, L. J. (2003). Public attitudes towards genetically-modified food. *British Food Journal*, 10(4), 246-262.

Oppenheim, A. N. (1992). Questionnaire design, interviewing and attitude measurement (new ed.). London; New York: Continuum International Publishing Group.

Paul, C., Mason, W. M., McCaffrey, D., & Fox, S.A. (2008). A cautionary case study of approaches to the treatment of missing data. *Statistical Methods and Applications*, 17, 351-372.

Petrić, B, & Cźarl, B. (2003). Validating a writing strategy questionnaire. *System*, *31*(2), 187-215.

Pin, R.R., & Gutteling, J.M. (2009). The development of public perception research in the genomics field. An empirical analysis of the literature on the field. *Science Communication*, *31*(1), 57-83.

Prokop, P., Lešková, A., Kubitako, M., & Diran, C. (2007). Slovakian students' knowledge of and attitudes toward biotechnology. *International Journal of Science Education*, *29*(7), 895-907.

Sáez, M.J., Niño, A.G., & Carretero, A. (2008). Matching society values: students' views of biotechnology. *International Journal of Science Education*, *30*(2), 167-183.

Sharma, S. (1996). *Applied multivariate techniques*. USA: John Wiley & Sons, Inc.

Uşak, M., Erdogan, M., Prokop, P., & Özel, M. (2009). High school and university students' knowledge and attitudes regarding biotechnology. *Biochemistry and Molecular Biology Education*, *37*(2), 123-130.

Wasserman, J. D., & Bracken, B.A. (2003). Psychometric characteristics of assessment procedures. In J. R. Graham, & J. A. Naglieri (Eds.), *Handbook of Psychology: Assessment psychology* (Vol. 10). (pp. 43-66). Hoboken, N J: John Wiley & Sons, Inc.

Subchapter 2

A statistical approach to quantitative data validation focused on the assessment of students' perceptions about biotechnology

Abstract

Student awareness levels are frequently used to evaluate the effectiveness of educational policies to promote scientific literacy. Over the last years several studies have been developed to assess students' perceptions towards science and technology, which usually rely on quantitative methods to achieve broad characterisations, and obtain quantifiable and comparable data. Although the usefulness of this information depends on its validity and reliability, validation is frequently neglected by researchers with limited background in statistics. In this context, we propose a guideline to implement a statistical approach to questionnaire validation, combining exploratory factor analysis and reliability analysis. The work focuses on the psychometric analysis of data provided by a questionnaire assessing 1196 elementary and high school students' perceptions about biotechnology. Procedural guidelines to enhance the efficiency of quantitative inquiry surveys are given, by discussing essential methodological aspects and relevant criteria to integrate theory into practice.

Introduction

It is widely acknowledged that while case-study methodologies are particularly appropriate for detailed studies, survey-based approaches can provide considerable amounts of data in comparatively shorter periods of time (Black, 1999). Moreover, the data made available are usually easier to process and suitable for prediction and generalisation (Oppenheim, 1992).

These features underlie the reasons why in large scale educational observatories such as the ROSE, the PISA and the TIMSS surveys, quantitative assessment is favoured. Among the various inquiry methods available, quantitative approaches such as questionnaire-based surveys allow a broad characterisation of the target population (Black, 1999; Oppenheim, 1992). However, these instruments hold limitations that are mainly related to biases introduced by the respondents' subjective interpretations and the researcher's expectations (Black, 1999). Hence, questionnaires must be designed and administered following adequate procedures to optimise the validity and reliability of the results they provide. Questionnaire validation, namely by adopting an integrated approach combining pilot study with psychometric analysis, allows improving the instrument's design and to address ambiguities that can compromise the quality of the data gathered (Black, 1999; Fabrigar et al., 1999; Oppenheim, 1992). Still, there are many studies in which these procedures are insufficiently or inappropriately reported (Blalock et al., 2008). For instance, Blalock et al. (2008) analysed 150 peer-reviewed articles published between 1935 and 2005 focusing on the measurement of students' attitudes towards science and verified that, from the 66 resulting instruments, 42% were missing evidence of their psychometric soundness. This may result from the seeming complexity of the available validation methods and from the erroneous perception that they are inefficient considering the extra time and effort demanded for their implementation (Dörnyei, 2002). However, if research designs overlook validation procedures, the resulting data will not allow for sound interpretation, reproducibility and comparison. Therefore, validation is a crucial topic in science education research.

In this context, this study proposes a guideline for the improvement of the quality of quantitative data by discussing a statistical approach to psychometric analysis, combining EFA and reliability analysis. The work presented focuses on the large scale evaluation of a multidimensional questionnaire, developed and validated to assess elementary and high school students' perceptions about biotechnology.

Exploratory factor analysis

EFA has become a frequently used statistical technique in psychometric analysis (Costello & Osborne, 2005; Fabrigar et al., 1999; Henson & Roberts, 2006). EFA is an exploratory method to probe data variations in search for a more limited set of variables, or factors that can explain the variability observed for the variables measured (Henson & Roberts, 2006). Through the combination of the predicted variables within the components identified, EFA allows to reduce the total number of variables to process. But, most importantly, this technique is an efficient tool to assess construct validity (Hayton et al., 2004) by allowing to quantify the extent to which the items measure the intended constructs (Groth-Marnat, 2009). Nevertheless, the empirically endorsed good practices in EFA require a considerable amount of decisions that are based upon contextual parameters rather than on clearly predetermined criteria (Child, 2006; Costello & Osborne, 2005; Hogarty et al., 2005). Among these decisions, the ones that most frequently concern researchers deal with the size of the sample used and the number of factors and items to retain (Costello & Osborne, 2005).

Context of the study

With the recognition of the range and depth of biotechnology's social repercussions, the concerns about the public understanding of biotechnology applications have fostered an increasing curricular coverage of biotechnology topics, and the development of numerous programs and resources to promote students' literacy (Dawson & Soames, 2006; Sáez et al., 2008). Across numerous countries, including Australia, The Netherlands, Slovenia and Turkey, the efficiency of this investment on biotechnology education has been mainly evaluated using quantitative instruments designed to assess the students' knowledge and attitudes towards this socio-scientific issue (Dawson & Soames, 2006; Klop & Severiens, 2007; Prokop et al., 2007; Uşak et al., 2009). However, more commonly that what could be expected, the instruments used are not psychometrically adequate, and the reported findings are based on data obtained using questionnaires that have not been properly validated (Erdogan et al., 2009). Besides affecting the validity of eventual comparisons established according to the indicators conveyed in these studies, this also compromises the reliability of the diagnostic assays, which ultimately impacts the success of intervention programs designed accordingly. These implications emphasise the need to further extend the array of studies focusing on students' perceptions of biotechnology using valid measurement instruments, and to assist researchers in making sense of the psychometric analysis methods available.

The integration of information obtained by measuring different elements that affect opinions and behaviours regarding biotechnology, such as knowledge, attitudes, interest, importance attributed to it and selection and use of information about it can contribute to a more thorough understanding of the factors that mediate students' perceptions. However, most of the studies addressing students' perceptions about biotechnology have generally covered knowledge and attitudes (Dawson, 2007; Klop & Severiens, 2007; Prokop et al., 2007; Uşak et al., 2009). A more limited number of studies has assessed students' interest about this socio-scientific issue (Kidman, 2008; Lamanauskas & Makarskaitė-Petkevičienė, 2008), and on the sources they most commonly use and trust to gather information about it (Cavanagh et al., 2004; Dawson, 2007; Gunter et al., 1998). Accordingly, the questionnaires that have been made available focus on the measurement of discrete elements. Furthermore, these instruments often lack empirical support of validity and reliability. So far, only a limited number of studies, as for instance the ones by Klop & Severiens (2007) and Erdogan et al. (2009), have clearly evidenced concerns with the psychometric soundness of the instruments used. If the existent questionnaires are not utterly appropriate to address the specificities of the target population or account for the entire topics one intends to investigate, it becomes necessary to develop novel instruments that must be thoroughly validated. In fact, validation must always be incorporated in a study's design, as these procedures report to specific settings and populations (Oppenheim, 1992). Therefore, aiming to obtain a broader and articulated appraisal of elements that mediate students' perceptions, a questionnaire was developed and validated through pilot work and psychometric analysis, to measure the following constructs: knowledge, attitudes, interest, importance given to biotechnology, and use and trust in information sources.

Purpose of the study

The main goal of this study was to present an oriented guideline for validating scores of quantitative instruments in applied settings, by focusing on the psychometric analysis of data gathered through the large-scale validation of a multi-dimensional questionnaire designed to measure elementary and high school students' perceptions about biotechnology. The procedure conducted followed a statistical approach combining a pilot study and psychometric analysis through EFA and reliability analysis. More than produce a valid instrument, this study discusses key issues that are determining for the improvement of the validity and reliability of quantitative survey data through exploratory factor analysis, such as:

- Deciding on the quantity of data to use and how to address missing values. After determining the sample size, the researcher must select the method(s) to treat missing data (Blalock et al., 2008).
- Deciding on a confirmatory or exploratory technique. The development of new instruments and/or the absence of a robust theoretical model supporting the instrument used, require the use of exploratory techniques (Worthington & Whittaker, 2006).
- Determining the fitness of the data to factor analysis. The researcher must always assess the factorability of the data set (Worthington & Whittaker, 2006).
- Deciding on how many factors and items to retain. The researcher must decide on the number of factors emerging from the analysis that explain the maximum amount of variance in the entire set of items, and the number of items that contribute effectively to those factors (Hayton et al., 2004; Hogarty et al., 2005).
- Assessing the scale's reliability. The extent to which the variance in the results can be attributed to the latent variable identified must be assessed (DeVellis, 2003).

The guidelines proposed to address these topics are emphasised in Fig. II.1.

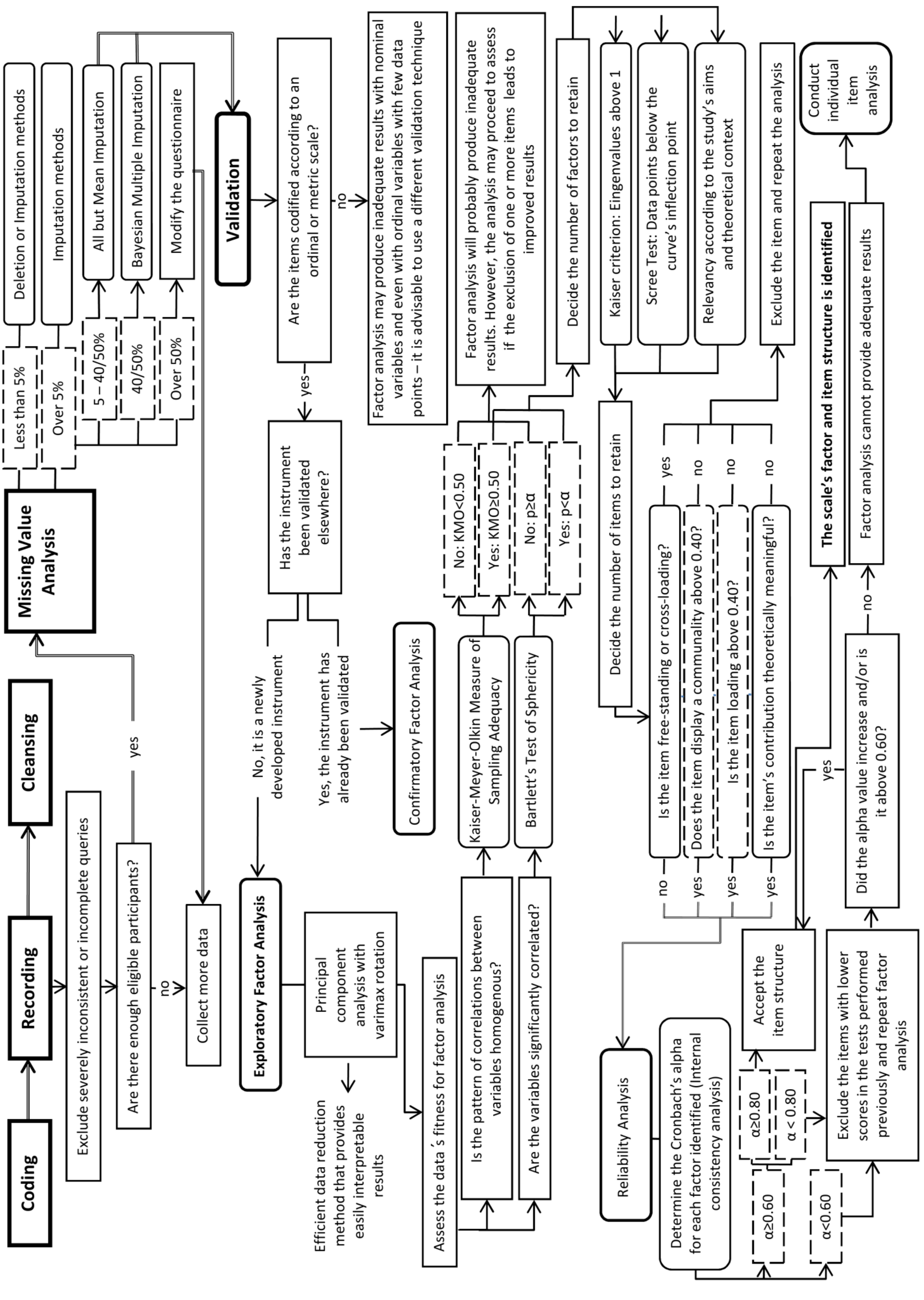

Fig. II.1. Methodological workflow proposed for the validation of data from newly developed quantitative assessment instruments through psychometric analysis, using exploratory factor analysis (principal component analysis with varimax rotation).

Method

Participants

This study involved 1196 students attending the last years of elementary (*n*=498) and high school (*n*=698) in nine randomly selected schools (seven public and two private schools) located in Porto metropolitan area. Students from the 9th grade(aged 14-15 years) and the 12th grade (aged 17-18 years) were asked to participate in this study because these are the final years of elementary and high school in Portugal, respectively, meaning that many students end these school cycles without further formal science education. The Portuguese high school curricular formats were considered for the inclusion of three subsets of high school students: (i) science students that were attending biology (*n*=210); (ii) science students that were not attending biology (*n*=225); and (iii) students engaged in non-science courses, such as arts, economics, informatics, or literature (*n*=263). The 9th graders' (56% females) mean age was 14.34 (*SD*=0.66) and the 12th graders' (53% females) mean age was 17.36 (*SD*=0.66).

Measurement instrument

Questionnaire development

The questionnaire was designed following a multistep approach consisting of: content definition; item pool selection; expert review; pilot study; and psychometric analysis of the pilot data (Oppenheim, 1992).

Content. The content covered in the questionnaire was defined based on a review of the literature on the assessment of students' awareness about biotechnology (namely Cavanagh et al., 2004; Dawson, 2007; Gunter et al., 1998; Klop & Severiens, 2007; Prokop et al., 2007) with the purpose of identifying existing surveys and topics requiring further analysis. Three criteria were considered:

- Authenticity - the contents are contextualised in the elementary and high school science curricula (DEB, 2001; DGIDC, 2004), and address issues frequently discussed in the media and in informal science education contexts.
- Intelligibility - the contents are accessible to students from different instructional levels and courses.
- Multidimensionality - the contents comprise diverse elements that prompt conceptual, cognitive, affective, behavioural and motivational engagement.

Item pool selection. The item pool was drafted by selecting items available in published studies (Cabo Hernández et al., 2006; Dawson, 2007; Dawson & Soames, 2006; Gaskell et al., 2006; Miles et al., 2005; Prokop et al., 2007) that were relevant for the measurement of the dimensions defined in light of the theoretical framework of the study, and adapting them according to the specificities of the study sample. Minimum sets of the most informative items were included in the questionnaire to improve its time and cost efficiency, by reducing its length while maintaining internal checks (Oppenheim, 1992).

Expert review. A preliminary version of the questionnaire was subjected to the scrutiny of two biology teachers, one microbiologist and one psychology researcher, to obtain feedback on content and face validity, and on the accuracy, intelligibility, adequacy and organisation of the items. The questionnaire's re-structuring heralded by this review resulted in the pilot version.

Pilot study and psychometric analysis of the pilot data. From October to December 2008, the pilot version of the questionnaire was administered to 92 elementary and high school students from four classes in three of the nine schools involved in the main study. The composition of the pilot sample was consistent with the main sample and included students from one 9th grade class, from one 12th grade biology class and from two 12th grade non-biology classes. The questionnaires were administered during class periods under the supervision of a teacher and/or an investigator. The students were instructed to ask and/or write down any questions concerning interpretation difficulties and uncertainty about words and concepts. It took them less than 15 minutes to complete the whole set of questions. At this stage, no major constraints demanding content or structural modifications in the questionnaire were identified. Using the SPSS v. 17.0, the data conveyed were subjected to EFA and to reliability analysis following the procedures described for the large-scale assessment study. EFA results led to the removal of three items and to the revision of several others. A detailed description of the pilot study is available in Fonseca, Costa, Lencastre, & Tavares (2010).

Questionnaire description

Following the psychometric analysis of the pilot data, a final version of the questionnaire was obtained (Table II.3). Part I of the instrument includes five factual data questions to determine the students' socio-demographic profile. Part II consists of 14 questions organised in six sections to assess knowledge, attitudes and interest about biotechnology, the importance given to it, and sources of information used and trusted.

The *knowledge* section includes: a multiple choice question asking students for a definition of biotechnology (Q1); a list of options from which they must select the biotechnology applications they know (Q2); and a True or False question addressing basic aspects about biotechnology applications (Q3), which includes a *Don't know* option to reduce the social desirability bias (Black, 1999). The *attitudes* section includes 25 five-point Likert-type items organised in three scales according to the tripartite attitude model (Klop and Severiens, 2007; Rosenberg and Hovland, 1960). The *cognitive component* scale (Q5) evaluates students' approval of different biotechnology applications. The *affective component* scale (Q6 except Q6c) assesses students' feelings about human embryo research, GM food labelling, and the capacity to control the consumption of GM foods. The *behavioral component* scale (Q7 and Q13) assesses students' intention to buy GM products, and to allow access to their genetic information. The *interest* section includes a five point Likert-type scale (Q8 and Q9) measuring students' interest directly and considering the frequency with which they are actively or passively exposed to information about biotechnology. The *importance* section consists in a five-point Likert type scale (Q4 and Q6c) measuring the importance students attribute to biotechnology in general and to the future impact of biomedical applications. The *sources of information* section is organised in two subsections to assess sources used (Q11) and trusted (Q12). The first subsection includes 11 options from which students must select the sources they most frequently use. In the second subsection students are asked to rate their trust in 14 different entities on a five-point Likert-type scale.

Table II.3
Questionnaire used.

SECTION / SCALE	EXAMPLES OF QUESTIONS/ ITEMS
Factual questions	School you are attending; Grade you are attending; Age; Sex; Course you are attending
Knowledge	Q1: Biotechnology can be defined as a set of processes… (Select the option you most agree with) (i)… in which recombinant DNA technology is used; (ii)… applied to investigation and product development; (iii)… which involves cell and tissue culture; (iv)… by which genetically modified organisms (GMOs) can be developed. Q2: From the biotechnological applications listed, select the one(s) you know. (i) Production of medicines and vaccines; (ii) Production of hormones; (iii) Production of organic products, such as milk or yogurt; (iv) Recovery of contaminated soils using genetically modified bacteria; ... (viii) Production of amminoacids and vitamins. Q3: Answer the following questions using True/False/I don't know. (a) All biotechnology applications are properly regulated; (b) The ingestion of GM foods can induce gene alterations; (c) There is evidence that GMOs can endanger the environment; (d) It is impossible to transfer genes from plants to animals; (e) Biotechnology allows transferring organs from GM animals to humans; (f) Cloning and genetic engineering are similar biotechnology processes; ... (o) Genetic manipulation techniques can allow to increase animal resistance to disease.
Importance	Q4: How important do you think biotechnology is to the quality of life? (1-Not at all important to 5-Very important)[a] Q6c: Rate your agreement with the following sentence (1-I disagree completely to 5-I agree completely): Do you agree that future generations will benefit from biotechnology medical applications?[a]
Attitudes – cognitive component	Q5: Rate your approval towards the following activities (1-I do not approve it at all to 5-I approve it completely). (a)Use of yeast in the production of bread, wine and beer[b]; (b)Use of yeast in animal food production[b]; (c)Use of genetically modified organisms in waste treatment; (d)Plant growth improvement in saline environments by gene alteration[c]; (e)Treatment of genetic disorders by embryonic gene manipulation; (f)Treatment of genetic disorders by human gene manipulation; (g)Insertion of plant genes into animals; (h)Utilization of genetically modified cows in the production of medicines for humans[d]; (i)Production of pesticide resistant plants by gene manipulation[c]; (j)Genetic modification of tomatoes to make them ripen more slowly and have a longer shelf life[c]; (k)Use of insulin produced by bacteria[d]; (l)Organ transplant from transgenic animals to humans[d]; (m)Use of human cloning with therapeutic purposes.
Attitudes – affective component	Q6: Rate your agreement with the following sentences (1-I totally disagree to 5-I totally agree). (a)It is our duty to authorise investigation that may lead to the development of more efficient medical treatments, even if it implies using embryonic stem cells[e]; (b)The labels of transgenic food should specify whether the food or any of its ingredients is genetically modified[f]; (d)It is wrong to use embryonic stem cells in biomedical research, even if it may contribute to the development of medical treatments[e]; (e)Each of us is capable of determining our intake of transgenic foods[f].
Attitudes – behavioural component	Q7: How often would you… (1-Never to 5-Always) (a)...buy transgenic foods if they were easily available in supermarkets[g]; (b)...buy medicines obtained by genetically manipulation[g]. Q13: How often would you… (1-Never to 5-Always) (a)...do a genetic test for medical diagnosis[h]; (b)...give the police access to your genetic information[h]; (c)...buy transgenic foods if they were healthier than other foods[g]; (d)...buy transgenic foods if they were less expensive than other foods[g].
Interest	Q8: Rate your interest towards biotechnology (1-I am not interested at all to 5-I am very interested)[i]. Q9: How often do you… (1-Never to 5-Many times) (a)…listen to news about biotechnology[i]; (b)…read articles or watch TV shows about technology[i]; (c)…search the web for subjects related to biotechnology[i].
Sources of information used	Q11: From which of the following sources do you most commonly obtain information about biotechnology? TV; Radio; Newspapers, Magazines; Scientific magazines; Internet; Textbooks; Teachers; Friends; Family; Others.
Trust in sources of information	Q12: Rate your trust in the following sources of information about biotechnology (1-I do not trust it/them at all to 5-I trust it/them completely): (a)Media; (b)Scientific magazines; (c)Pharmaceutical industry[j]; (d)Agro-food industry[j]; (e)Health industry[j]; (f)Governmental agencies; (g)Universities; (h)Scientists; (i)Internet; (j)Environmental organisations[k]; (k)Consumer rights organisations[k]; (l)European Union; (m)Medical doctors; (n)Politicians.

The items identified with the same letter (a,b,…k) contribute to the same factor.
The questionnaire includes two items that were not considered in the analysis: Q10 asking students to evaluate their understanding of news about biotechnology and Q14 inquiring about the interest of the questionnaire. The full version is available upon request from the authors.

Data collection and analyses

The fieldwork was conducted from January to April 2009, by administering the questionnaire in the respondents' native language, during classes under the supervision of a teacher and/or a researcher. From the 1244 students originally asked to participate in the study, 48 had to be excluded as their answers were severely incomplete or inconsistent. Using SPSS v. 17.0, the data collected from 1196 students were codified, recorded and cleansed. Descriptive and missing values analyses were performed for all the items in the questionnaire, followed by validity and reliability analyses.

Construct validity. Each of the scales included in the questionnaire was subjected to EFA (PCA with varimax rotation), following the procedures described in Fig. II.1. The number of factors to retain during factor analysis was decided based on the Kaiser criterion (eigenvalues greater than 1), the scree test and meaningfulness of the results according to the theoretical framework (Costello & Osborne, 2005; Hayton et al., 2004). The analysis included items that were not freestanding, cross-loading or decreasing the scale's internal consistency, and that displayed acceptable communalities (above 0.40), with factor pattern/structure coefficients above 0.40 (Costello & Osborne, 2005; Fabrigar et al., 1999; Hogarty et al., 2005; Sharma, 1996). In performing EFA, the Kaiser-Meyer-Olkin measure of sampling adequacy and the Bartlett's Test of Sphericity were used to assess the suitability of the sample for factor analysis (Worthington & Whittaker, 2006).

Reliability. Following EFA, an internal consistency analysis was performed by determining the Cronbach's coefficient alpha for each factor identified (DeVellis, 2003).

Cross-validation. The consistency of these analyses was assessed through cross-validation (Hastie et al., 2009), by repeating the procedures for two independent sub-samples resulting from aleatory bipartition of the main sample and for the four subsets in which it can be divided according to grade and curricular structure: 9^{th} graders, 12^{th} grade science students attending biology; 12^{th} grade science students not attending biology; and 12^{th} graders from other courses. The two cross validation sub-samples were obtained by organising the database according to the different groups that can be defined by the respondents' grade, course, school and gender and by randomly attributing the code 1 or 2 to half of the individuals of each group.

Dichotomous items. The *knowledge* section and the *sources of information used* subsection, include dichotomous items that were not subjected to factor analysis. Decisions on item retention and adequacy regarding these sections were made according to the outcomes of missing values analysis (Kent, 2001), and considering the Kuder-Richardson (KR20) coefficient scores. Item difficulty and item discrimination indexes were determined for each item in the knowledge section, allowing the assessment of the questionnaire's ability to distinguish between the different academic profile-based groups (Netemeyer et al., 2003).

Inferential statistics. The students' responses were examined and compared by performing Student's *t*-tests and ANOVA analysis. One-sample *t*-tests were used to compare the students' mean responses with the midpoint of the test variables (test value=3). For a confidence interval of 95%, responses that were below, above or equal to 3 were considered indicative of a negative, positive and neutral positioning, respectively. Correlations between variables were assessed using Pearson's product-moment correlation coefficient.

Results and Discussion

Understanding the psychometric properties of the instruments used in quantitative research is a key element in making sense of the data that they provide. Based on the data gathered during the large scale implementation of the questionnaire developed, this section presents evidence of the influence of validation on the interpretation of the results obtained. Since this paper discusses the implications of psychometric analysis for a comprehensive understanding of the findings according to the theoretical framework and the interactions between the variables, the detailed description of this survey's outcomes is beyond the focus of this study and can be found in Fonseca, Costa, Leonor, & Tavares (2011).

Missing values analysis

Following the missing values analysis performed, all the questionnaires' items were considered eligible for analysis. The maximum score of missing cases registered was 2.3% and occurred for item Q1 (Table II.3), which had already displayed the lowest response rate in the pilot study (4.3%). For the items subjected to EFA, this score decreased to 2.0% and occurred for the item Q5c (Table II.3). The series mean method in SPSS was used to replace the missing values, given that they were limited (below 5%) and random (Paul et al., 2008).

Dichotomous items

Knowledge

The KR20 score for the knowledge section was 0.55. The KR20 formula provides an estimate of internal consistency for inventories with dichotomous items, which is interpreted like the Cronbach alpha scores (Gravetter & Forzano, 2009; Guion & Highhouse, 2006). Ranging from 0.00 to 1.00, KR20 scores must be greater than 0.60 for a measure to be considered reliable (Hair et al., 1998; Wasserman & Bracken, 2003). However, since the KR20 coefficient provides minimum reliability estimates and the difficulty of the items in this section is heterogeneous (Black, 1999; Guion & Highhouse, 2006), all items were upheld for analysis. The difficulty of the *knowledge* items varied from 22% to 87%, averaging 49%. The item difficulty index is the fraction of correct answers per item and its optimum value is usually considered to be halfway between 100% of correct answers for that item and the chance probability of getting the answer correct (Kaplan & Saccuzzo, 2009). Therefore, the scores obtained indicate the possibility to differentiate several levels of student knowledge. The mean item discrimination value was 0.31, ranging from 0.18 to 0.44, with item Q3a scoring below 0.05. Item discrimination measures the degree of correspondence between the success in each item and in the whole set of items and can be computed using a point biserial correlation (Kaplan and Saccuzzo, 2009). The correlation values must be above 0.30 for items to be considered sufficiently discriminating (Kaplan & Saccuzzo, 2009).Although the scores obtained may suggest a weak discriminatory capacity, the item difficulty index together with the ANOVA results for the *Knowledge Score* (0 to 24 points) obtained by combining the selection of the most inclusive option in question Q1 (option ii, Table II.3), the number of correct answers in Q3 (Table II.3) and the number of biotechnology applications known by each student (Q2, Table II.3) demonstrates the questionnaire's capacity to distinguish between the four academic profile-based groups sampled (F(3.1192)=50.78, p=0.00) (*Supporting information - Table II.S1*). These results revealed a hierarchic distribution of knowledge levels according to the biology coverage of each group's curricula, with the science students who attended biology scoring significantly higher than the other students (p=0.00), followed by the science students who did not attend biology and finally the non-science students and the 9th graders, between whom no significant differences were observed (p=0.40).

Sources of information used

The relevance of the information made available in this subsection, along with the impossibility to measure it efficiently as a single dimension (Guion & Highhouse, 2006) supported the decision to analyse all the items, in spite of the low internal consistency score obtained (KR20=0.51). The selection patterns for the sources of information were significantly dependent on the students´ academic profile (χ^2(33)=416.95, p=0.00) (*Supporting information - Fig. II.S1*), demonstrating the questionnaire's ability to distinguish between different academic profile-based groups.

Scales

Considering that the scales in this questionnaire were newly developed, their validation was conducted through EFA (Worthington & Whittaker, 2006). From the existing extraction procedures for EFA, PCA, and common factor analysis have become the two most frequently used, and there has been disagreement among statisticians about the advantages and limitations of each (Costello & Osborne, 2005; Worthington & Whittaker, 2006). In this study, PCA was selected as the extraction method considering that: (i) in most contexts, both methods have been shown to produce similar results (Fabrigar et al., 1999); (ii) PCA is the default option in most statistical software packages, such as SPSS and SAS (Statistical Analysis System), and consequently, more easily available; (iii) compared with PCA, the outcomes of common factor analysis pertain more effectively to confirmatory factor analysis, making it appropriate for studies for which there is a utterly established theoretical model (Floyd & Widaman, 1995). Concerning the rotation method used, both orthogonal and oblique rotation methods were tested, producing identical outcomes regarding the factor pattern/structure correlations. Since the interpretation of rotated component matrixes is simpler, it was decided to present the outcomes of varimax rotation (orthogonal) (Costello & Osborne, 2005; Henson & Roberts, 2006).

Attitudes' cognitive component scale

According to the pilot study data, this scale includes three factors: *classical applications* (Q5a and Q5b, α=0.64.); *agro-food applications* (Q5d, Q5i, and Q5j, α=0.62); and *biomedical applications* (Q5h, Q5k, and Q5l, α=0.67). The factor structure identified for this scale in the large-scale evaluation is consistent with this three-factor solution (Table II.4), and explains 64.47% of the total variance observed. The KMO score was 0.80, confirming the sample's adequacy for factor analysis (KMO=0.80). The KMO provides a measure of homogeneity between variables, by comparing partial correlations coefficients with the observed correlation coefficients (Worthington & Whittaker, 2006), and it should be greater than 0.50 for a satisfactory factor analysis to proceed (Sharma, 1996). Furthermore, Barlett's Test of Sphericity shows a statistically significant correlation between the variables (χ^2(28)=2010.08, p=0.00). This test allows assessing the quality of the correlation matrix, by testing the null hypothesis that it is an identity matrix. Significant scores for the Bartlett's Test (p<0.05) indicate that there is a correlation pattern among the variables tested (Ho, 2006). In addition, the Cronbach's alpha values are all satisfactory, scoring above 0.60. Cronbach's alpha provides an average estimate of all possible split-half correlations obtained by dividing a scale in every possible way. Scores vary from 0.00 to 1.00 and must be greater than 0.60 for a measure to be considered reliable (Hair et al., 1998; Wasserman & Bracken, 2003). Thus, it was decided to keep this factor structure and analyse the data accordingly. However, given that this sample (n=1196) has approximately 13 fold the size of the sample used in the pilot study (n=92), it is important to mention that this increase did not affect the quality of the factor solution identified.

The factors' mean scores (Table II.4) reveal a hierarchic approval of the three different types of applications considered (p<0.01), with classical applications being considered the most acceptable, followed by agro-food applications, and with biomedical applications being disapproved by the majority of students. This is an unexpected result considering that usually biomedical applications are perceived as more acceptable than agro-food applications (Klop & Severiens, 2007; Sáez et al., 2008). Since two of the three items contributing to the factor *biomedical applications* mention animal manipulation (Q5h and Q5l, Table II.4), which is known to elicit negative attitudes (Dawson, 2007; Einsiedel, 2005), it is possible that the students' positioning towards biomedical applications is a response to the type of organism manipulated rather than to the purpose of the application. In fact, individual item analysis shows that the mean scores for both of these items were significantly lower than 3, whereas item Q5k (Table II.4), addressing bacterial manipulation, scored significantly above 3 in the five-point scale used. These outcomes demonstrate the impact of the content of the items used in the students' responses. Most importantly, they assert the importance of considering the multidimensionality of the variables measured, which would not be evident by conducting a simple reliability analysis of all the items included in the *cognitive component* scale. In this case, the Cronbach alpha value obtained would be satisfactory (α=0.81) and the global mean score for the scale would be indicative of a positive cognitive appraisal (M=3.27, SD=0.65, t(1195)=14.44, p=0.00). However, these results would overlook differential attitudinal responses, emphasising the need to consider a scale's factor structure as finer information that shapes the global information provided by that scale.

Table II.4

Factor structure of the *cognitive component of attitudes* scale based on EFA and reliability analysis

Item	h^2	Identifiable Factors: *Classical applications*	*Agro-food applications*	*Biomedical applications*	One sample *t*-test (test value=3): *M*	*SD*	*t*(1195)	*p*
Q5a. Use of yeast in the production of bread, wine and beer	0.75	0.85			3.76	1.15	23.04	0.00
Q5b. Use of yeast in animal food production	0.69	0.79			3.33	1.15	10.06	0.00
Q5d. Plant growth improvement in saline environments by gene alteration	0.66		0.81		3.56	1.11	17.56	0.00
Q5i. Production of pesticide resistant plants by gene manipulation	0.66		0.77		3.45	1.24	13.89	0.00
Q5j. Genetic modification of tomatoes to make them ripen more slowly and have a longer shelf life	0.48		0.61		2.74	1.26	-7.18	0.00
Q5h. Utilisation of genetically modified cows in the production of medicines for humans	0.58			0.65	2.61	1.20	-11.2	0.00
Q5k. Use of insulin produced by bacteria	0.62			0.71	3.33	1.25	9.13	0.00
Q5l. Organ transplant from transgenic animals to humans	0.71			0.84	2.71	1.31	-7.53	0.00
Eigenvalue		1.00	3.09	1.06				
% of variance		12.54	38.68	13.25				
Cronbach's alpha		0.64	0.66	0.67				
M		3.52	3.25	2.90				
SD		0.98	0.90	0.98				
t(1195)		19.32	9.64	-4.08				
p		0.00	0.00	0.00				

EFA - exploratory factor analysis. Coefficients below 0.30 were suppressed. KMO=0.80. Bartlett's Test of Sphericity: $\chi^2(28)=2010.08$, $p=0.00$. h^2 - communality coefficient. *M* - Mean. *SD* - Standard Deviation.

The best factor structure obtained for this scale excludes five items that were included in the questionnaire to address the cognitive component of students' attitudes (Table II.3). However, failing to analyse these variables can result in a meaningful loss of information. For instance, in spite of their overall negative response to biomedical applications, the students were particularly optimistic towards biomedical applications involving gene alterations in humans (*M*=3.91, *SD*=1.07, *t*(1195)=29.53, *p*=0.00), and even specifically in embryos (*M*=3.73, *SD*=1.22, *t*(1195)=20.57, *p*=0.00). Therefore, aiming to grasp a clearer picture of the students' cognitive appraisal of biotechnology, a possibility would be to analyse and interpret their answers to these items along with the factors identified (Maruish, 1999).

Attitudes' affective component scale

According to the factor structure identified during the pilot data processing, this scale includes two factors: *human embryo research* (Q6a and Q6d, α=0.37); and *control capacity* (Q6b and Q6e, α=0.33). The best factor solution obtained by EFA corroborates this two-factor structure (Table II.5) and accounts for 58.73% of the variance observed. However, these results are not supported by the reliability analysis, as the factors included in the scale do not display acceptable internal consistency (scoring below 0.50*)*. Moreover, despite the statistically significant correlation between the variables ($\chi^2(6)=142.99$*,* p=0.00), the KMO index (KMO=0.49) indicates a disperse pattern of correlations among them (Sharma, 1996), suggesting that the items' formulation leads this dimension to be unfit for factor analysis. In fact, the KMO score obtained for the pilot sample (KMO=0.45) was also at the threshold of acceptability, suggesting that the increase in the sample size does not affect its suitability for this method. Whereas these results may be interpreted as tendencies when a relatively small sample is used, they become unacceptable for a sample of 1196 individuals. Therefore, this factor structure should not be considered.

This outcome is not surprising, given the also low internal consistency scores registered during the psychometric analysis of the pilot study's data. A solution to overcome this situation involves assessing this dimension by individual item analysis (Maruish, 1999). Alternatively, the scale's reliability could be improved by increasing the number of items contributing for the two factors identified (Black, 1999; Kent, 2001). Nevertheless, this option was dismissed during the validation phase, as a longer questionnaire would be unsuitable considering the features of the target population (Dörnyei, 2002; Oppenheim, 1992). It must be emphasised that the measurement of students' affective responses to biotechnology, obtained through the examination of these individual items, demands their interpretation as tendencies requiring further development on their consistency.

Table II.5
Factor structure of the a*ffective component of attitudes* scale based on EFA and reliability analysis.

Item	h^2	Identifiable Factors: *Human embryo research*	Identifiable Factors: *Control capacity*	One sample *t*-test (test value=3): *M*	*SD*	*t*(1195)	*p*
Q6a. It is our duty to authorise investigation that may lead to the development of more efficient medical treatments, even if it implies using embryonic stem cells	0.67	0.80		2.98	1.23	-0.63	0.52
*Q6d. It is wrong to use embryonic stem cells in biomedical research, even if it may contribute to the development of medical treatments **(R)***	0.69	0.82		2.98	1.27	-0.55	0.58
Q6b. The labels of transgenic food should specify whether the food or any of its ingredients is genetically modified	0.37		0.61	4.62	0.80	69.83	0.00
Q6e. Each of us is capable of determining our intake of transgenic foods	0.63		0.79	3.01	1.22	0.33	0.74
Eigenvalue		1.33	1.02				
% of variance		33.30	25.43				
Cronbach's alpha		0.48	0.03				
M		3.00	2.19				
SD		1.02	0.74				
t(1195)		-0.04	-37.88				
p		0.97	0.00				

EFA - exploratory factor analysis. Coefficients below 0.30 were suppressed. KMO=0.49. Bartlett's Test of Sphericity: $\chi^2(6)=142.99$, $p=0.00$. h^2 - communality coefficient. *M* - Mean. *SD* - Standard Deviation. R - reversely coded item.

Attitudes' behavioural component scale

According to the pilot data, this scale has a two-factor structure - *buying intent* (Q7a, Q7b, Q13c, and Q13d), α=0.63) and *access to genetic information* (Q13a and Q13b, α=0.69). The best factor solution identified during the large scale evaluation is consistent with this two-factor scale (Table II.6) and explains 61.00% of the total variance observed. The sample adequacy is confirmed by the KMO score (KMO=0.74) and the Bartlett's Test of Sphericity demonstrates that the variables are statistically significantly correlated ($\chi^2(15)=1378.22$, $p=0.00$). However, the Cronbach's alpha value for the factor *access to genetic information* is below the threshold of acceptability (α=0.56). Consequently, the two items that contribute to this factor must be assessed individually.

Accordingly, their individual analysis reveals that the differences in the two items' responses were conspicuous enough to prevent their treatment and interpretation as a single underlying variable. Specifically, as seen in Table II.6, most students would agree on doing a genetic test for medical purposes, but were reluctant towards the prospect of giving the authorities access to their genetic information.

Table II.6
Factor structure of the *behavioural component of attitudes* scale based on EFA and reliability analysis.

Item	h^2	Identifiable Factors: *Buying intent*	Identifiable Factors: *Access to genetic information*	One sample *t*-test (test value=3): *M*	*SD*	*t*(1195)	*p*
Q7a. Buy transgenic foods if they were easily available in supermarkets	0.71	0.84		2.78	1.05	-7.17	0.00
Q7b. Buy medicines obtained by genetic manipulation	0.59	0.77		2.93	1.07	-2.24	0.03
Q13c. Buy transgenic foods if they were healthier than other foods	0.55	0.57		3.51	1.16	15.28	0.00
Q13d. Buy transgenic foods if they were less expensive than other foods	0.49	0.67		2.53	1.21	-13.55	0.00
Q13a. Do a genetic test for medical diagnosis	0.67		0.81	3.35	1.22	9.98	0.00
Q13b. Give the police access to your genetic information	0.65		0.80	2.48	1.22	-14.69	0.00
	Eigenvalue	2.51	1.15				
	% of variance	41.83	19.17				
	Cronbach's alpha	0.72	0.56				
	M	2.94	2.92				
	SD	0.83	1.02				
	t(1195)	-2.594	-2.83				
	p	0.01	0.01				

EFA - exploratory factor analysis. Coefficients below 0.30 were suppressed. KMO=0.74. Bartlett's Test of Sphericity: $\chi^2(15)=1378.22$, $p=0.00$. h^2 - communality coefficient. *M* - Mean. *SD* - Standard Deviation.

Interest about biotechnology scale

EFA results for the pilot data indicate this is a uni-factor scale (Q8, Q9a, Q9b, and Q9c, $\alpha=0.77$). The large scale evaluation results corroborate this solution (Table II.7), which explains 62.90% of the total variance observed. There is a statistically significant correlation between the variables tested ($\chi^2(6)=1511.78$, $p=0.00$) and the KMO index supports the sample's adequacy

(KMO=0.77). Furthermore, the scale's reliability (α=0.80) justifies the retention of this factor structure and the analysis of the items that it includes. An important feature of this interest scale is the fact that there is only one item inquiring students directly about their interest in biotechnology (Q8, Table II.7), whereas there are three items assessing the frequency with which they are passively or actively involved in searching information about it (Q9, Table II.7). This structure allows minimising the social desirability bias (Black, 1999).

Table II.7
Factor structure of the *interest about biotechnology* scale based on EFA and reliability analysis.

		Identifiable Factor	One sample *t*-test (test value=3)			
Item	h^2	*Interest about biotechnology*	*M*	*SD*	*t*(1195)	*p*
Q8. Rate your interest towards biotechnology	0.54	0.74	3.23	1.09	7.12	0.00
Q9a. Listen to news about biotechnology	0.62	0.79	2.61	1.07	-12.74	0.00
Q9b. Read articles or watch TV shows about biotechnology	0.73	0.85	2.66	1.16	-10.02	0.00
Q9c. Search the web for subjects related to biotechnology	0.66	0.80	2.09	1.10	-28.44	0.00
Eigenvalue		2.52				
% of variance		62.90				
Cronbach's alpha		0.80				
M		2.65				
SD		0.88				
t(1195)		13.93				
p		0.00				

EFA - exploratory factor analysis. Coefficients below 0.30 were suppressed. KMO=0.77. Bartlett's Test of Sphericity: $\chi^2(6)$=1511.78, *p*=0.00. h^2 - communality coefficient. *M* - Mean. *SD* - Standard Deviation.

Trust in sources of information scale

The psychometric analysis of the pilot data indicates that this scale has a two-factor structure - *industry* (Q13c, Q13d, and Q13e, α=0.63); and *non-governmental organisations* (Q13j and Q13k, α=0.67), which is supported by EFA outcomes using the main student sample (Table II.8). This two-factor solution explains 69.06% of the total variance observed. The sample's adequacy was confirmed (KMO=0.67) as well as the significance of the correlations between variables ($\chi^2(10)=1190.81$, $p=0.00$). In addition, the reliability scores are above the threshold of acceptability (Table II.8). Thus, it was decided to consider this two-factor solution. Yet, the questionnaire includes nine others items that do not contribute to this scale's factor structure (Table II.3). Consistently with what was decided for the cognitive component of attitudes, the individual analysis of these items should be considered.

Given the diversity of information sources listed in Q12 (Table II.3), it would be unreasonable to assume that all the items would fit into a uni-factor structure, although it could be expected that the level of trust placed in different sources would converge into groups defined according to features such as target-audience or purpose (for example educational, legislative or outreach). To some extent EFA outcomes support this assertion, by demonstrating that the variation patterns in the trust placed by students in the pharmaceutical (Q12c), agro-food (Q12d), and health (Q12e) industries, and in environmental organisations (Q12j) and human-rights organisations (Q12k) are similar enough for each of the two sets to be analysed as a single factor (Table II.8). Regarding the individual items in question Q12 (Table II.3), EFA results demonstrate that the underlying aspects in each of these items that elicit different appraisals of trust cannot be disregarded by conducting a global assessment (*Supporting information - Table II.S2*).

Table II.8
Factor structure for the *trust in sources of information* scale based on EFA and reliability analysis.

		Identifiable Factors		One sample *t*-test (test value=3)			
Item	h^2	*Industry*	*Non-governmental organizations*	*M*	*SD*	*t*(1195)	*p*
Q13c. Pharmaceutical industry	0.64	0.80		4.24	0.81	52.79	0.00
Q13d. Agro-food industry	0.66	0.80		3.75	0.91	28.51	0.00
Q13e. Health industry	0.68	0.82		3.13	0.87	5.29	0.00
Q13j. Environmental organizations	0.74		0.85	3.55	0.96	19.90	0.00
Q13k. Consumer rights organizations	0.74		0.85	3.72	0.94	26.14	0.00
Eigenvalue		2.23	1.23				
% of variance		44.52	24.54				
Cronbach's alpha		0.74	0.64				
M		3.52	3.63				
SD		0.73	0.82				
t(1195)		24.46	26.90				
p		0.00	0.00				

EFA - exploratory factor analysis. Coefficients below 0.30 were suppressed. KMO=0.67. Bartlett's Test of Sphericity: $\chi^2(10)=119.81$, $p=0.00$. h^2 - communality coefficient. *M* - Mean. *SD* - Standard Deviation.

Importance of biotechnology scale

EFA results for this scale with the main study data conform to a uni-factor structure (Table II.9) that explains 65.15% of the total variance observed and is consistent with the solution identified using the pilot study data (Q4 and Q6c, α=0.56). However, similarly to what was observed for the *affective component of attitudes* scale, the reliability score does not support this factor solution (α=0.46). Likewise, this scale also seems to be inadequate for factor analysis, given that, although the variables are statistically significantly correlated ($\chi^2(1)$=114.89, p=0.00), the KMO value is at the threshold of acceptability (KMO=0.50). For these reasons, the items Q4 and Q6c (Table II.9) must be analysed independently. Whereas the first item provides a direct assessment of the importance given to biotechnology, the second can be used as supplementary information, namely to be crossed with data from the attitudes *cognitive component* scale concerning biomedical applications.

Table II.9
Factor structure for the *importance of biotechnology* scale based on EFA and reliability analysis.

		Identifiable Factor	One sample *t*-test (test value=3)			
Item	h^2	*Importance of biotechnology*	*M*	*SD*	$t(1195)$	*p*
Q4. How important do you think biotechnology is to the quality of life?	0.65	0.81	3.75	0.81	32.08	0.00
Q6c. Do you agree that future generations will benefit from biotechnology medical applications?	0.65	0.81	3.99	0.95	36.24	0.00
Eigenvalue		1.30				
% of variance		65.15				
Cronbach's alpha		0.46				
M		3.87				
SD		0.71				
$t(1195)$		42.48				
p		0.00				

EFA - exploratory factor analysis. Coefficients below 0.30 were suppressed. KMO=0.50. Bartlett's Test of Sphericity: $\chi^2(1)$=114.89, p=0.00. h^2 - communality coefficient. *M* - Mean. *SD* - Standard Deviation

Articulating EFA results with the theoretical background: interpretation and implications

Most of the instruments used to measure student attitudes towards biotechnology, regardless of the concept definition considered, have envisaged this as a uni-dimensional construct (Dawson & Schibeci, 2003; Erdogan et al., 2009). Only recently Klop & Severiens (2009) have demonstrated that a tripartite model, underpinned by the interplay between cognitive, affective and behavioural elements, allows a more thorough description of students' attitudinal responses to biotechnology applications. Consistently with the tripartite model, EFA outcomes using the pilot data and the main study's data revealed items' structures that conform to three different scales. However, this result would not be evident simply by conducting a reliability analysis of all the attitudes items, as the Cronbach alpha value obtained would be satisfactory (α=0.82). This reasoning applies to each of the three attitude scales defined, and demonstrates that the awareness of a scale's factor structure enables the researcher to conduct a sounder interpretation of the constructs measured than the one achievable through a global appraisal. Considering the tripartite attitude model, although knowledge can exert a positive influence, the development of a certain attitude towards biotechnology relies on emotional and behavioral elements based on personal weighing of risks and benefits, as well as ethical implications (Brossard & Nisbet, 2007; Verdume & Viaene, 2003). In this study, the different constructs measured were subjected to correlation analysis and its outcomes were interpreted according to the reference values available in De Vaus (2002): correlations scoring below 0.30, between 0.30 and 0.50, or above 0.50, were considered low, moderate or large, respectively. Taking this into consideration, knowledge was found to be positively correlated with cognitive, affective and behavioral attitudinal components (p<0.01). The correlations identified between the variables included in each of these domains (*Supporting information - Table II.S3*) suggest that the development of perceptions about biotechnology applications depends upon an intricate network of attitudinal elements that modulate the expression of knowledge (Amin et al., 2007; Klop & Severiens, 2007; Sáez et al., 2008). For instance, although associated with knowledge (r=0.25, n=1196, p=0.00), the intention to purchase GM products was more strongly correlated with the students' beliefs about agro-food (r=0.45, n=1196, p=0.00) and biomedical (r=0.46, n=1196, p=0.00) applications. Similarly, the students' emotional engagement with human embryo research (item Q6a, r=0.35, n=1196, p=0.00) had a higher influence than their content knowledge (r=0.118, n=1196, p=0.00) on the approval of genetic manipulation of embryonic cells (item Q5e, Table II.3). In addition to attitudes, motivational elements are also important determinants of people's behaviours. Student interest about, and importance attributed to biotechnology were measured in this study because these are endogenous and exogenous determinants of motivational patterns, respectively (Ryan & Deci, 2000). EFA results revealed a uni-factor *interest* scale, according to which students were not interested about biotechnology (Table II.7), and two individual items indicating that students perceived biotechnology in general and biomedical applications in particular as important issues for the improvement of the quality of life (Table II.9). The positive correlations identified between the variables interest, general importance of biotechnology (r=0.40, n=1196, p=0.00), and importance of biomedical applications (r=0.22, n=1196, p=0.00), indicate that students are more interested in biotechnology issues that they consider important. In addition, these dimensions were also positively correlated with the students' *Knowledge Score* (interest: r=0.36, n=1196, p=0.00; importance: r=0.27, n=1196, p=0.00). Further research on the correlation patterns identified between the dimensions measured would foster their transposition into causal relationships, informing practitioners and curriculum developers of the most efficient interventional measures.

Cross validation

The outcomes of the cross validation procedures confirm the results obtained using the main student sample (*Supporting information - Tables II.S4 and II.S5*). The best solutions identified for the two subsets obtained by aleatory division of the main sample were straightforward asserting. When the sample was divided into four groups according to the student's grade and curricular structure, the variations of the scales' internal consistency demanded a more careful and adjusted selection of the number of factors and items to retain. To a certain extent this variability could be predicted considering the heterogeneity of the participants' academic profiles among these four groups.

Overall, the factor structures for each of the scales in the questionnaire identified during the large-scale evaluation (Tables II.4-II.9) are consistent with the ones previously identified with the pilot sample (n=92). Likewise, the cross-validation procedures carried out also lead to these factor solutions (*Supporting information - Tables II.S4 and II.S5*). Although the increase in the number of respondents might have been expected to produce a sounder factor structure, this was not observed. Furthermore, the EFA results were only partially supported by the outcomes of the reliability analysis. Consequently, the factor structures that showed poor reliability should not be upheld. Therefore, as stated above, individual items have to be used to assess the affective component of the students' attitudes towards biotechnology, the importance they give to it, and their opinion on allowing access to their genetic information (behavioural component). All the other items subjected to factor analysis can be analysed according to the structures identified.

Although there is not a specific procedure to determine the adequate sample size for EFA (Reise et al., 2000), criteria such as keeping a minimum 2:1 ratio between the number of subjects and variables assessed (Meyers et al., 2006), or having a minimum of 100 effective participants (Child, 2006; Wasserman & Bracken, 2003) are considered reasonable. Nevertheless, regardless of the criteria considered, it is acknowledged that samples must be sufficiently large to allow minimising sampling errors, obtaining stable estimates, and producing robust statistical analyses (Wasserman & Bracken, 2003). This study's findings corroborate the premise that sample adequacy for EFA rests on practical decisions concerning desired levels of statistical significance and meaningful analytic contributions for the theoretical aims of the study (Costello & Osborne, 2005; Henson & Roberts, 2006). Furthermore, they emphasise that the EFA's efficiency depends not only on the number of individuals providing the data (Costello & Osborne, 2005; Fabrigar et al., 1999), but also on their homogeneity concerning features such as age or education**.** In addition, these outcomes also indicate that even with representative samples, extrapolations must be cautious and rational (Child, 2006). The sample used in this study was heterogeneous in regards to the participants' academic background. Although cross validation using the four key groups that compose the main sample ultimately confirmed the best factor structures identified, the variability of the results obtained between groups suggests that the sample's composition is clearly a conditioning factor. This heterogeneity can also explain why the factor structures identified were not as clear as what might be expected considering the size of the sample (Child, 2006; Costello & Osborne, 2005). It is acknowledged that these scores may be a consequence of the low number of items contributing to the factors considered. Yet, the possibility to increase the number of items may not be an option, as a longer questionnaire can be inappropriate for the target population. In this case, presenting students within this age range with a longer questionnaire is likely to foster their impatience, resulting in their lack of engagement, which would jeopardize the reliability of their answers (Dörnyei, 2002; Oppenheim, 1992).

The psychometric analysis described and the features of the student population, assert the importance of including individual items in the analyses so that a better characterisation can be achieved. It is necessary to keep in mind that EFA is an approach that requires adopting a pragmatic position and deciding upon the articulation of results that frequently do not fit perfectly into the existing criteria (Fabrigar et al., 1999). Therefore, its outcomes are influenced by several factors, namely the design of the study, its aims or the data's properties (Costello & Osborne, 2005). For instance, even if a more parsimonious interpretation of the data is achievable through factor analysis, it is imperative to interpret its results according to the theoretical framework in which the study was designed (Hayton et al., 2004). Practical decisions that affect the efficiency of EFA, such as factor and item retention or the size of the sample to be used, cannot be devoid of theory. Despite its limitations, this statistical method is a powerful tool to identify latent variables that can account for the variance observed for certain psychological features, to better understand the correlations between the variables, and to integrate the results obtained within theoretical constructs (Henson & Roberts, 2006). In this study, EFA proved to be of the utmost importance in allowing to focus the data analysis on underlying constructs that were not obvious in the original design, in improving the interpretation of the results according to the existing theoretical frameworks and in bringing to the fore a multidimensional characterisation of students perceptions about biotechnology according to key psychometric features.

Conclusions and Implications for science education research

This study reinforces the notion that the forecasts made available by EFA are affected by sample size and composition, and that the use of larger samples does not necessarily yield better results (Hogarty et al., 2005; Reise et al., 2000). Most importantly, it demonstrates that the decisions required in psychometric analysis are not straightforward and depend on the nature of the study design, the goals set, and the properties of the data collected.

The questionnaire used in this study allows obtaining a broad characterisation of elementary and high school students' perceptions about biotechnology with reasonable validity and reliability. Furthermore, because the samples used in the pilot and in the large-scale assessment study comprise students from diverse academic backgrounds within a wide age range, this questionnaire is suitable for implementation in a variety of instructional situations and contexts. In addition, by allowing data collection in a single application, this instrument is a time-efficient option even for studies with tight research agendas. However, more than presenting the science education research community with a novel quantitative measurement instrument, this work contributes with the definition of a procedural guideline for studies framed within the scope of quantitative assessment that can be applied to the improvement of the validity and reliability of the data collected in diverse evaluative settings. In this context, it must be mentioned that this study does not seek to produce a better or generally more suitable instrument than the biotechnology knowledge inventories and attitudes scales available in published research. Likewise, the validation procedure presented is not exclusive nor to be applied in every science education survey developmental study. This work provides an insightful perspective on an efficient and easily available validation procedure that has wide applicability in quantitative research. It contributes to demonstrate that psychometric analysis methods are not impervious statistical techniques that may seem unappealing and complex to unacquainted researchers.

The data of the large-scale implementation study (Fonseca et al., 2011) have been applied to the development of hands-on activities to improve high school students' scientific literacy (Fonseca & Tavares, 2011a,b). The instrument's multi-dimensional features fostered the cross-examination of the dimensions evaluated in order to design the most suitable experimental activities, namely concerning criteria such as authenticity, intelligibility, motivation and engagement.

It would be interesting to apply the questionnaire in different countries to assess public perceptions about biotechnology in both student and adult populations. Since this questionnaire covers general topics that are not exclusively curricular-derived, it can be used with populations from various backgrounds. It is possible to further develop the instrument, namely by increasing the number of items for the factors with low internal consistency scores, so that its reliability can be improved. According to the features of the target population and the research plan, the various scales comprised in this larger questionnaire could be administered separately, or in differently combined fashions. In fact, the *attitude*, the *sources of information used*, and the *sources of information trusted* scales were used in a study focusing on biology teachers' beliefs about biotechnology and biotechnology education

(Fonseca, Costa, Lencastre, & Tavares, 2012). Finally, it would be important for other researchers to implement this proposed guideline using their own instruments and datasets at pilot or post-implementation stages. By allowing them to scrutinize their data, this will give them a deeper understanding of its quality and intricacies, thus improving the results and the generalisations made.

Acknowledgements

The authors are grateful to all the participant teachers and students that contributed to gather the data presented and to Catarina L. Santos for useful comments and suggestions on the manuscript. Maria João Fonseca is supported by the FCT fellowship SFRH/BD/37389/2007.

References

Amin, L., Jahi, J., Nor, A. R., Osman, M., & Mahadi, N. M. (2007). Public acceptance of modern biotechnology. *Asia Pacific Journal of Molecular Biology and Biotechnology, 15*(2), 39-51.

Black, T. R. (1999). *Doing quantitative research in the social sciences. An integrated approach to research design, measurement and statistics*. London: SAGE Publications.

Blalock, C. L., Lichtenstein, M. J., Owen, S., Pruski, L., Marshall, C., & Toepperwein, M. (2008). In pursuit of validity: a comprehensive review of science attitude instruments 1935–2005. *International Journal of Science Education, 30*(7), 961-977.

Brossard, D., & Nisbet, M. C. (2007). Deference to scientific authority among a low information public: understanding U.S. opinion on agricultural biotechnology. *International Journal of Public Opinion Research, 19*(1), 24-52.

Cabo Hernández, J. M., Enrique Mirón, C., & Cortiñas Jurado, J. R. (2006). Opiniones e intenciones del professorado sobre la participación social en ciência y tecnología. El caso de la biotecnologia. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias*. *3*(3), 349-369.

Cavanagh, H., Hood, J., & Wilkinson, J. (2004). Riverina high school students' views of biotechnology. *Electronic Journal of Biotechnology, 8*(2), 1-7.

Child, D. (2006). *The essentials of factor analysis*. New York: Continuum International Publishing Group.

Costello, A. B., & Osborne, J. W. (2005). Best practices in exploratory factor analysis: four recommendations for getting the most from your analysis. *Practical Assessment, Research and Evaluation, 10*(7). Retrieved from http://pareonline.net/getvn.asp?v=10andn=7

Dawson, V. (2007). An exploration of high school (12–17 year old) students' understandings of, and attitudes towards biotechnology processes. *Research in Science Education, 37*(1), 59-73.

Dawson, V., & Schibeci, R. (2003). Western Australian school students' understanding of biotechnology. *International Journal of Science Education, 25*(1), 57-69.

Dawson, V., & Soames, C. (2006). The effect of biotechnology education on Australian high school students' understandings and attitudes about biotechnology processes. *Research in Science and Technological Education, 24*(2), 183-198.

Departamento da Educação Básica. (2001). *Orientações curriculares do ensino básico - ciências físicas e naturais*. Lisboa: Ministério da Educação.

DeVellis, R. F. (2003). *Scale development. Theory and applications* (2nd ed.). Thousand Oaks, CA: Sage Publications.

Direcção-Geral de Inovação e Desenvolvimento Curricular. (2004). *Programa de biologia 12º ano. curso científico-humanístico de ciências e tecnologias.* Lisboa: Ministério da Educação.

Dörnyei, Z. (2002). *Questionnaires in second language research: construction, administration, and processing*. New Jersey: Lawrence Erlbaum Associates.

Einsiedel, E. F. (2005). Public perceptions of transgenic animals. *Revue Scientifique et Technique-Office International Des Epizooties 24*(1), 149-157.

Erdogan, M., Özel, M., Uşak, M., & Prokop, P. (2009). Development and validation of an instrument to measure university students' biotechnology attitude. *Journal of Science Education and Technology, 18*(3), 255-264.

Fabrigar, L. R., Wegener, D. T., MacCallum, R. C., & Strahan, E. J. (1999). Evaluating the use of exploratory factor analysis in psychological research. *Psychological Methods, 4*(3), 272-299.

Floyd, F. J., & Widaman, K. F. (1995). Factor analysis in the development and refinement of clinical assessment instruments. *Psychological Assessment, 7*(3), 286-299.

Fonseca, M. J., Costa, P., Lencastre, L., & Tavares, F. (2010). Assessing assessment tools: towards questionnaire improvement through validation. In In G. Cakmakci & M.F. Taşar (Eds.), *Contemporary science education research: learning and assessment* (pp. 259-266). Ankara, Turkey: Pegem Akademi.

Fonseca, M. J., Costa, P., Lencastre, L., & Tavares, F. (2011). Multidimensional analysis of high school students' perceptions about biotechnology. *Journal of Biological Education*, 46(3), 129-139.

Fonseca, M. J., Costa, P., Lencastre, L., & Tavares, F. (2012). Disclosing biology teachers' beliefs about biotechnology and biotechnology education. *Teaching and Teacher Education*. 28: 368-381.

Fonseca, M. J., & Tavares, F. (2011a). Natural antibiotics: a hands-on activity on garlic's antibiotic properties. *American Biology Teacher*. 73(6), 342-346.

Fonseca, M. J., & Tavares, F. (2011b). The bactericidal effect of sunlight. *The American Biology Teacher*. 73(9), 548-552.

Gaskell, G., Stares, S., Allansdottir, A., Allum, N., Corchero, C., Fischler, ...Wagner, W. (2006). *Europeans and biotechnology in 2005: Patterns and trends. Final report on Eurobarometer 64.3.* Brussels: European Commission's Directorate-General for Research.

Gravetter, F. J., & Forzano, L. B. (2009). *Research methods for the behavioral sciences* (3rd ed.). Belmont, CA: Wadsworth Cengage Learning.

Groth-Marnat, G. (2009). *Handbook of psychological assessment* (5th ed.). Hoboken, NJ: John Wiley and Sons, Inc.

Guion, R. M., & Highhouse, S. (2006). *Essentials of personnel assessment and selection*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Gunter, B., Kinderlerer, J., & Beyleveld, D. (1998). Teenagers and biotechnology: a survey of understanding and opinion in Britain. *Studies in Science Education, 32*(1), 81 - 112.

Hair, J. F., Anderson, R. E., Tatham, R. L., & Black, W. C. (1998). *Multivariate data analysis* (5th ed.). New Jersey: Prentice-Hall.

Hastie, T., Tibshirani, R., & Friedman, J. (2009). *The elements of statistical learning: data mining, inference, and prediction* (2nd ed.). New York: Springer.

Hayton, J. C., Allen, D. G., & Scarpello, V. (2004). Factor retention decisions in exploratory factor analysis: a tutorial on parallel analysis. *Organizational Research Methods, 7*(2), 191-205.

Henson, R. K., & Roberts, J. K. (2006). Use of exploratory factor analysis in published research. Common errors and some comment on improved practice. *Educational and Psychological Measurement, 66*(3), 393-416.

Ho, R. (2006). *Handbook of univariate and multivariate data analysis and interpretation with SPSS*. Boca Raton, FL: Taylor and Francis Group.

Hogarty, K. Y., Hynes, C. V., Kromrey, J. D., Ferron, J. M., & Mumford, K. R. (2005). The quality of factor solutions in exploratory factor analysis: The influence of sample size, communality and overdetermination. *Educational and Psychological Measurement, 65*(2), 202-226.

Kaplan, R. M., & Saccuzzo, D. P. (2009). *Psychological testing. Principles, applications, and issues* (7th ed.). Belmont, CA: Wadsworth Cengage Learning.

Kent, R. A. (2001). *Data construction and data analysis for survey research*. New York: Palgrave Macmillan.

Kidman, G. (2008). Asking students: What key ideas would make classroom biology interesting? *Teaching Science, 54*(2), 34-38.

Klop, T., & Severiens, S. (2007). An exploration of attitudes towards modern biotechnology: a study among Dutch secondary school students. *International Journal of Science Education, 29*(5), 663-679.

Lamanauskas, V., & Makarskaitė-Petkevičienė, R. (2008). Lithuanian university students' knowledge of biotechnology and their attitudes to the taught subject. *Eurasia Journal of Mathematics, Science and Technology Education, 4*(3), 269-277.

Maruish, M.E. (2004). *The use of psychological testing for treatment planning and outcomes assessment* (Vol. 3). (2nd ed.). London: Routledge.

Meyers, L. S., Gamst, G., & Guarino, A. J. (2006). *Applied multivariate research: design and interpretation*. London: SAGE Publications, Inc.

Miles, S., Ueland, Oslash, Øydis, & Frewer, L. J. (2005). Public attitudes towards genetically-modified food. *British Food Journal, 107*, 246-262.

Netemeyer, R. G., Bearden, W. O., & Sharma, S. (2003). *Scaling procedures. Issues and applications*. Thousand Oaks, CA: Sage Publications, Inc.

Oppenheim, A. N. (1992). *Questionnaire design, interviewing and attitude measurement* (New ed.). London; New York: Continuum.

Paul, C., Mason, W., McCaffrey, D., & Fox, S. (2008). A cautionary case study of approaches to the treatment of missing data. *Statistical Methods and Applications, 17*(3), 351-372.

Prokop, P., Lesková, A., Kubiatko, M., & Diran, C. (2007). Slovakian students' knowledge of and attitudes toward biotechnology. *International Journal of Science Education, 29*(7), 895 - 907.

Reise, S. P., Waller, N. G., & Comrey, A. L. (2000). Factor analysis and scale revision. *Psychological Assessment,, 12*(3), 287-297.

Rosenberg, M. J., & Hovland, C. I. (1960). Cognitive, affective, and behavioral components of attitudes. In C. I. Hovland & M. J. Rosenberg (Eds.), *Attitude organization and change: An analysis of consistency among attitude components* (pp. 1-14). New Haven, CT: Yale University Press.

Ryan, R. M., & Deci, E. L. (2000). Intrinsic and extrinsic motivations: Classic definitions and new directions. *Contemporary Educational Psychology, 25*(1), 54-67.

Sáez, M. J., Niño, A. G., & Carretero, A. (2008). Matching society values: Students' views of biotechnology. *International Journal of Science Education, 30*(2), 167-183.

Sharma, S. (1996). *Applied multivariate techniques*. New York: Jonh Wiley and Sons, Inc.

Uşak, M., Erdogan, M., Prokop, P., & Özel, M. (2009). High school and university students' knowledge and attitudes regarding biotechnology. *Biochemistry and Molecular Biology Education, 37*(2), 123-130.

Verdume, A., & Viaene, J. (2003). Exploring and modelling consumer attitudes towards genetically modified food. *Qualitative Market Research: An International Journal, 6*(2), 95-110.

Wasserman, J. D., & Bracken, B. A. (2003). Psychometric characteristics of assessment procedures. In J. R. Graham, & J. A. Naglieri (Ed.), *Handbook of psychology: assessment psychology* (Vol. 10, pp. 43-66). Hoboken, NJ: John Wiley and Sons, Inc.

Worthington, R. L., & Whittaker, T. A. (2006). Scale development research: A Content Analysis and Recommendations for Best Practices. *The Counseling Psychologist, 34*(6), 806-838.

Supporting information

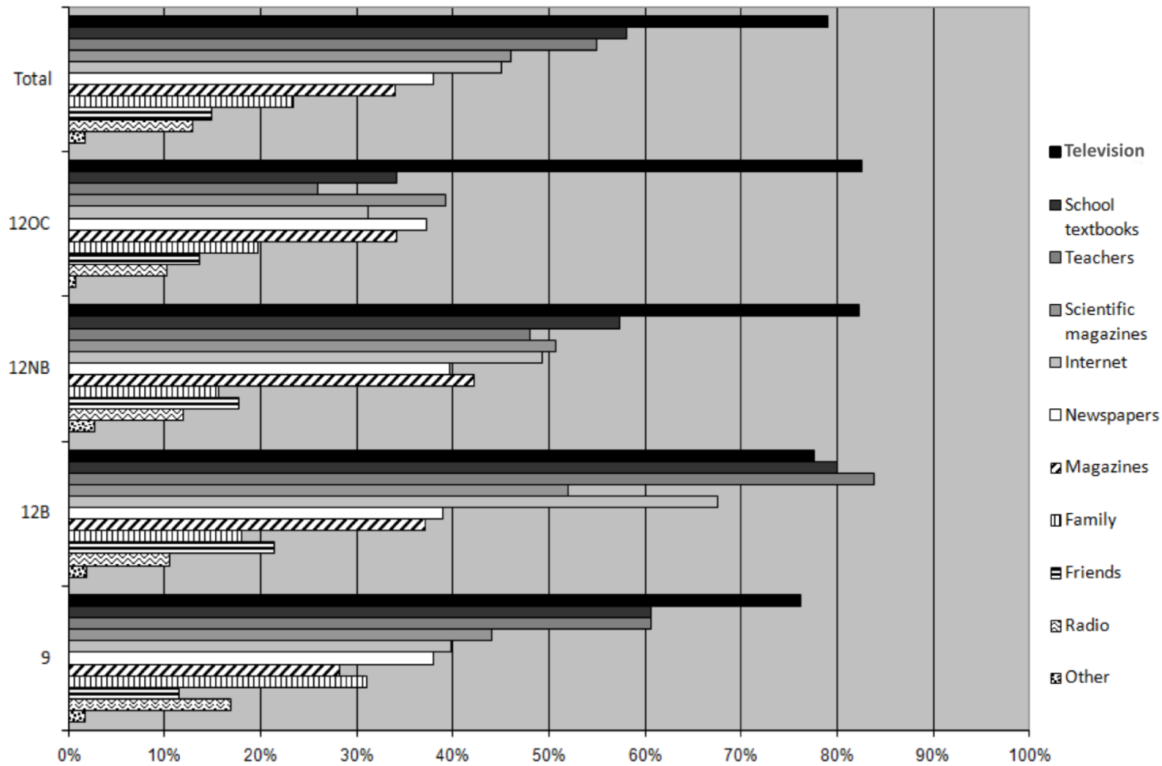

Fig. II.S1. Main sources of information about biotechnology used by students.
12OC – 12th graders from non-science courses, 12NB – 12th grade science students attending biology, 12B – 12th grade science students attending biology, 9 – 9th graders.

Table II.S1

Students' knowledge about biotechnology.

Percentage of students selecting the broadest option in question Q1, mean number of applications listed in Q2 known by students, mean number of correct answers in question Q3, and mean knowledge score values.

	Total	**12OC**	**12NB**	**12B**	**9**	***F*(3,1992)**	***p***
Q1							
Q1.Option ii	31.30%	21.30%	38.20%	53.30%	24.10%		
Q1.Other options	66.40%	77.60%	58.10%	45.70%	73.00%		
Q1.DK/NA	2.30%	1.10%	3.60%	1,00%	3.00%		
Q2							
M	4.15	3.95[b]	4.39[a,b]	4.50[a]	4.00[b]	6.62	0.00
SD	1.75	1.95	1.58	1.58	1.67		
Q3							
M	6.98	6.13[c]	7.45[b]	8.55[a]	6.44[c]	44.53	0.00
SD	2.62	2.63	2.71	2.28	2.38		
Knowledge Score							
M	11.44	10.48[c]	12.22[b]	13.58[a]	10.69[c]	50.78	0.00
SD	3.47	3.47	3.54	3.02	3.13		

12OC - 12th graders from non-science courses. 12NB - 12th grade science students not attending biology. 12B - 12th grade science students attending biology. 9 - 9th graders. DK/NA - *Don't know*/No answer. *M* - Mean. *SD* - Standard Deviation. a, b, c – different letters indicate significant differences for α=0.05. See Table 1 for the full items' description.

Table II.S2
Students' trust in sources of information about biotechnology.

		TOTAL	12OC	12NB	12B	9	*F*(3,1992)	*p*
Q12a. Media	*M*	3.37	3.26[b]	3.22[b]	3.33[b]	3.51[a]	7.57	0.00
	SD	0.90	0.89	0.90	0.85	0.91		
Q12b. Scientific	*M*	4.24	4.08[c]	4.28[b]	4.50[a]	4.20[c]	11.36	0.00
magazines	*SD*	0.81	0.80	0.78	0.66	0.87		
Industry	*M*	3.52	3.41[b]	3.47[a,b]	3.57[a]	3.57[a]	3.72	0.01
	SD	0.73	0.76	0.711	0.71	0.72		
Q12f. Governmental	*M*	2.74	2.69	2.71	2.66	2.82	1.69	0.17
agencies	*SD*	1.02	1.00	1.04	1.03	1.00		
Q12g. Universities	*M*	3.79	3.65[b]	3.95[a]	4.06[a]	3.69[b]	13.17	0.00
	SD	0.90	0.90	0.82	0.85	0.93		
Q12h. Scientists	*M*	4.14	4.04[b]	4.20[a]	4.22[a]	4.13[a,b]	2.24	0.08
	SD	0.86	0.85	0.77	0.81	0.92		
Q12i. Internet	*M*	2.90	2.78[b]	2.86[a,b]	2.93[a,b]	2.98[a]	2.97	0.03
	SD	0.91	8.55	0.86	0.90	0.97		
Non-governmental	*M*	3.63	3.68[a]	3.52[b]	3.58[a,b]	3.68[a]	2.43	0.06
organizations	*SD*	0.82	0.84	0.78	0.82	0.81		
Q12l. European Union	*M*	3.43	3.35	3.50	3.49	3.42	1.36	0.255
	SD	0.96	1.00	0.91	0.92	0.98		
Q12m. Medical doctors	*M*	3.84	3.59[b]	3.79[a,b]	3.94[a]	3.94[a]	9.99	0.00
	SD	0.91	0.95	0.89	0.91	0.91		
Q12n. Politicians	*M*	1.91	1.88	1.91	1.80	1.97	1.48	0.22
	SD	1.01	0.97	1.02	0.89	1.07		

12OC - 12th graders from non-science courses. 12NB - 12th grade science students not attending biology. 12B - 12th grade science students attending biology. 9 - 9th graders. *M* - Mean. *SD* - Standard Deviation. a, b, c – different letters indicate significant differences for α=0.05.

Table II.S3

Pearson product-moment correlations between knowledge and attitudes towards biotechnology (n=1196).

	ATCOGII	ATCOGIII	ATCOGIV	ATCOGV	ATCOGVI	ATCOGVII	ATCOGVIII	ATAFE I	ATAFEII	ATAFEIII	ATBEHAI	ATBEHAII	ATBEHAIII	KNOWLEDGE
Classical applications (ATCOGI)	0.39**	0.36**	0.29**	0.08**	0.19**	0.22**	0.01	0.08**	0.11**	-0.02	0.27**	0.09**	0.06*	0.29**
Agro-food applications (ATCOGII)		0.46**	0.37**	0.28**	0.30**	0.33**	0.17**	0.22**	0.09**	-0.11**	0.45**	0.12**	0.09**	0.25**
Biomedical applications (ATCOGIII)			0.41**	0.22**	0.26**	0.47**	0.27**	0.23**	0.04	-0.03	0.46**	0.13**	0.13**	0.36**
Use of GM microorganisms in waste treatment (ATCOGIV)				0.24**	0.27**	0.17**	0.11**	0.15**	0.15**	0.01	0.31**	0.12**	0.13**	0.28**
Therapeutic embryonic gene manipulation (ATCOGV)					0.59**	0.17**	0.25**	0.35**	0.05	-0.04	0.27**	0.07*	0.05	0.12**
Therapeutic human gene manipulation (ATCOGVI)						0.20**	0.24**	0.25**	0.13**	-0.03	0.32**	0.13**	0.04	0.19**
Insertion of plant genes into animals (ATCOGVII)							0.25**	0.22**	-0.02	-0.05	0.32**	0.07*	0.12**	0.15**
Therapeutic human cloning (ATCOGVIII)								0.33**	-0.10**	-0.17**	0.22**	0.07*	0.08**	0.01
Human embryo research (ATAFEI)									-0.03	-0.10**	0.27**	0.04	0.08**	0.08**
GM food labeling (ATAFEII)										0.012	0.03	0.10**	-0.01	0.13**
Control over dietary levels of GM foods (ATAFEIII)											-0.08**	-0.02	-0.09**	0.02
Intention to purchase GM products (ATBEHAI)												0.30**	0.28**	0.25**
Diagnostic genetic testing (ATBEHA)													0.39**	0.16**
Giving the police access to one's genetic information (ATBEHAIII)													1	0.03

* indicates significant differences for α=0.05; ** indicates significant differences for α=0.01.

Table II.S4
Cross validation results using two aleatory sub-samples.

		Sub-sample 1				Sub-sample 2			
Scale	Identifiable factors	KMO	Eigenvalue	% Variance	Cronbach's alpha	KMO	Eigenvalue	% Variance	Cronbach's alpha
Attitudes Cognitive component	Classical applications	0.77	1.02	12.72	0.59	0.81	1.01	12.57	0.68
	Agro-food applications		2.98	37.21	0.64		3.16	39.50	0.67
	Biomedical applications		1.09	13.64	0.69		1.04	13.03	0.65
Affective component	Human embryo research	0.46	1.34	33.44	0.50	0.51	1.33	33.24	0.46
	Control capacity		1.08	26.88	0.08		1.01	25.28	0.03
Behavioural component	Buying intent	0.71	2.41	40.12	0.70	0.75	2.61	43.42	0.73
	Access to genetic information		1.17	59.54	0.53		1.13	18.79	0.58
Interest		0.77	2.48	62.11	0.80	0.77	2.54	63.41	0.81
Trust in sources of information	Industry	0.67	2.24	44.86	0.75	0.67	2.21	44.27	0.74
	Non-governmental organisations		1.20	23.91	0.62		1.26	25.24	0.66
Importance		0.50	1.35	67.65	0.52	0.50	1.24	62.14	0.39

For simplification purposes, the table does not include information regarding the items that contribute to the factors displayed. The item structure for each factor identified during this analysis is consistent with the one obtained using the main sample. The Bartlett's Test of Sphericity for each scale is acceptable ($p<0.001$).

Table II.S5

Cross validation results using 4 sub-samples: 9th graders; 12th grade science students attending biology; 12th grade science students that are not attending biology; and 12th graders from other courses.

Scale	Identifiable factors	12th grade science non-biology students				12th grade science biology students			
		KMO	Eigenvalue	% Variance	Cronbach's alpha	KMO	Eigenvalue	% Variance	Cronbach's alpha
Attitudes' Cognitive component	Classical applications	0.77	0.91	11.35	0.52	0.79	1.03	12.85	0.52
	Agro-food applications		3.18	39.78	0.62		3.02	37.80	0.74
	Biomedical applications		1.23	15.36	0.74		1.03	12.93	0.59
Attitudes' Affective component	Human embryo research	0.50	1.56	38.94	0.69	0.49	1.47	36.77	0.59
	Control capacity		1.14	28.40	0.30		1.00	25.00	0.020
Attitudes´ Behavioural component	Buying intent	0.71	2.59	43.24	0.73	0.74	2.50	41.68	0.75
	Access to genetic information		1.18	19.66	0.50		1.19	19.75	0.50
Interest		0.73	2.37	59.27	0.77	0.70	2.23	5.75	0.73
Trust in sources of information	Industry	0.65	2.23	44.52	0.74	0.64	2.24	44.88	0.75
	Non-governmental organisations		1.26	25.27	0.64		1.30	25.97	0.70
Importance		0.50	1.31	65.23	0.47	0.50	1.25	62.33	0.38

For simplification purposes, the table does not include information regarding the items that contribute to the factors displayed. The item structure for each factor identified during this analysis is consistent with the one obtained using the main sample. The Bartlett's Test of Sphericity for each scale is acceptable ($p<0.001$).

Table II.S5 (continued)

SCALE	IDENTIFIABLE FACTORS	12TH GRADE NON SCIENCE STUDENTS KMO	Eigenvalue	% Variance	Cronbach's alpha	9TH GRADE STUDENTS KMO	Eigenvalue	% Variance	Cronbach's alpha
Attitudes' Cognitive component	Classical applications	0.71	1.04	13.05	0.75	0.73	0.99	12.40	0.51
	Agro-food applications		1.21	15.14	0.67		2.56	32.01	0.60
	Biomedical applications		2.91	36.31	0.60		1.22	15.25	0.60
Attitudes' Affective component	Human embryo research	0.49	1.28	31.96	0.42	0.49	1.22	30.45	0.35
	Control capacity		1.03	25.77	0.05		1.06	26.46	0.08
Attitudes´ Behavioural component	Buying intent	0.75	2.60	43.26	0.71	0.70	2.36	39.34	0.68
	Access to genetic information		1.12	18.67	0.59		1.18	19.67	0.59
Interest		0.76	2.45	61.22	0.79	0.78	2.48	61.98	0.80
Trust in sources of information	Industry	0.68	2.35	46.96	0.81	0.68	2.17	43.29	0.70
	Non-governmental organisations		1.31	26.22	0.65		1.16	23.12	0.62
Importance		0.50	1.26	63.22	0.41	0.50	1.29	64.53	0.45

For simplification purposes, the table does not include information regarding the items that contribute to the factors displayed. The item structure for each factor identified during this analysis is consistent with the one obtained using the main sample. The Bartlett's Test of Sphericity for each scale is acceptable (*p*<0.001).

CHAPTER III

Multidimensional analysis of high school students' perceptions about biotechnology

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Journal of Biological Education 2012
46(3), 129-139

Chapter III

Multidimensional analysis of high school students' perceptions about biotechnology

Abstract

Concerns about public understanding of biotechnology have motivated educational initiatives to improve students' competency to make scientifically sustained decisions regarding controversial issues. Understanding students' perceptions about biotechnology is essential to determine the effectiveness of these programmes. To assess how students' perceptions are modulated, this study evaluates education and gender effects on knowledge, attitudes, interest, and importance given to biotechnology. Following a quantitative assessment approach, a questionnaire was administered to 698 high school students engaged in three curricular formats: science students attending biology *(n*=210); non-biology science students (*n*=225); and non-science students (*n*=263). The outcomes of this study suggest that education is more determining than gender in shaping students' perceptions and behavioural intentions, which are modulated by cognitive, affective and motivational elements. Students, particularly from non-science courses, revealed knowledge and interest limitations, but acknowledged the importance of biotechnology. Most students demonstrated positive attitudes towards different applications, except when animal manipulation was involved. Positive correlations between knowledge, attitudes, interest and importance attributed to biotechnology were identified. The implications of these findings are discussed.

Introduction

Biotechnology's increasing social impact demands that citizens are able to understand its main concepts and make informed decisions regarding its applications in their daily lives. With the controversy surrounding biotechnology applications continuously fuelling public debate, the concerns about the public's understanding of their implications spread to the educational field, resulting in the curricular incorporation of biotechnology topics (Hanegan & Bigler, 2009; Steele & Aubusson, 2004) and the development of countless resources to improve students' scientific literacy (Milne & Morrison, 2007; Rothhaar, Pittendrigh, & Orvis, 2006). However, worldwide studies reveal that students still have knowledge limitations and negative attitudes towards biotechnology (Dawson, 2007; Prokop, Lesková, Kubiatko, & Diran, 2007; Sáez, Niño, & Carretero, 2008). The seeming inefficiency of the educational policies that have been implemented may be related with the fact that student populations are still poorly characterised in regards to their perceptions about biotechnology (Dawson, 2007; Prokop et al., 2007; Sáez et al., 2008; Uşak, Erdogan, Prokop, & Özel, 2009). Most studies conducted over the last decade to assess public perceptions about biotechnology have focused on adult populations (Hagelin 2004; Klerck & Sweeney, 2007; Pin & Gutteling, 2009). Furthermore, the few that have addressed young people's perceptions have mainly considered discrete elements, particularly knowledge and/or attitudes (Dawson, 2007; Lamanauskas & Makarskaitė-Petkevičienė, 2008; Prokop et al., 2007; Uşak et al., 2009). In this context, this study contributes to a more thorough understanding of factors mediating students' perceptions about biotechnology. It provides a comprehensive analysis of different elements that determine students' opinions and behaviours and evaluates the extent to which they are affected by gender and education. Perceptions are understood herein as students' overall appraisal of the impact, usefulness and limitations of biotechnology, as modulated by the interaction between their knowledge, attitudes, and motivational features, specifically interest and importance, towards the subject. This shall allow defining guidelines to improve biotechnology education at high school.

The conceptual framework presented was set following a review of relevant literature on elements that affect the development of opinions and behaviours concerning biotechnology.

Knowledge and attitudes towards biotechnology

Student knowledge of biotechnology, usually defined as rational and evidential content knowledge about key concepts and procedures, has been consistently described as insufficient and erroneous (Dawson, 2007; Prokop et al., 2007; Uşak et al., 2009). In contrast, student attitudes towards biotechnology, which have been measured according to risk and benefit perception, beliefs or general appraisals of acceptability (Dawson, 2007; Klop & Severiens, 2007), have been reported to vary from outright support to absolute rejection (Dawson, 2007; Klop & Severiens 2007; Sáez et al., 2008). The existence of a positive correlation between knowledge and attitudes has also yielded much debate. Although several authors confirm this correlation (Prokop et al., 2007; Sturgis, Cooper, & Fife-schaw, 2005), others claim that it does not always exist (Klop & Severiens, 2007; Verdume & Viaene, 2003), implying that knowledge about biotechnology does not necessarily reflect on acceptance, positive beliefs or perceptions of increased benefit/decreased risk. This unclear relation may result from the complexity of attitudinal responses. Attitudes are multidimensional constructs, determined by cognitive, affective and behavioural factors, which has led to a theoretical tripartite attitude model (Rosenberg & Hovland, 1960) that has been shown to suitably integrate the diversity of students' attitudinal responses to biotechnology (Klop & Severiens, 2007). Therefore, it is important to investigate the impact of knowledge on the different cognitive, affective and behavioural elements that shape the attitudinal expression.

Interest and importance attributed to biotechnology

Studying young people's perceptions about biotechnology within an educational context requires appraising additional elements besides knowledge and attitudes. The inclusion of biotechnology in high school curricula and the media coverage of biotechnology-related topics demand that students' interest about this subject and the importance they attribute to it are assessed (Harms, 2002; Kidman, 2008). There are a few studies describing students' interest in biotechnology as limited (Kidman, 2008; Lamanauskas & Makarskaitė-Petkevičienė, 2008), whereas others reveal their positive opinions about the importance of technological applications (The Gallup Organization, 2009; Sjøberg & Schreiner, 2006). Since interest and importance contribute, respectively, to intrinsic and extrinsic motivational patterns that are determining factors in learning and behaviour (Ryan & Deci, 2000), understanding how these two dimensions interact with each other and with knowledge and attitudes provides a baseline for the design of improved education strategies.

Purpose

To unveil the articulation between factors mediating students' perceptions, this study provides an integrative multidimensional analysis of high school students' knowledge, attitudes, interest, and importance attributed to biotechnology. Furthermore, it examines gender and education effects on students' perceptions, to obtain a sounder appraisal of their development process, and to draw guidelines for science education research and practice. To achieve these goals, the following research questions were formulated: is there a significant correlation between knowledge and attitudes towards biotechnology? Are students interested in biotechnology? Do they think biotechnology is important? How do the parameters assessed relate with each other? Are there relevant gender and academic profile-related differences in students' perceptions about biotechnology?

Method

Participants

This study involved 698 high school students from eight schools (seven public and two private schools) located in Porto metropolitan area. Participant schools were selected randomly and all 12th grade (17-18 year old) students were assessed. Students from this instructional level were recruited because this is the last year of high school, and many students end this school cycle without further contacts with formal science education. Moreover, according to the Portuguese Ministry of Education (DGIDC, 2004), this is the academic year when biotechnology-related contents are particularly emphasised. Since 2009, compulsory schooling in Portugal, like in other European countries **(**Education, Audiovisual and Culture Executive Agency [EACEA] 2009) comprises 12 years organised in three cycles of elementary education, and a secondary schooling cycle of three years, herein referred to as high school. Upon entering high school, students select the area they want to major in, which may not include science and technology (S&T) and, specifically, biology. Considering Portuguese high school curricular formats, three subsets of students were included: (i) S&T biology students (n=210); (ii) S&T non-biology students (n=225); and (iii) students attending non-S&T courses, such as arts, economics, or literature (n=263). The students (54% females) age ranged from 16 to 22 (M=17.360, SD=0.664).

Questionnaire

The questionnaire used (Fig. III.1) was designed following a multistep approach consisting in: content definition; item pool selection; expert review; pilot study; and psychometric analysis of the pilot data. Content definition was based on an exhaustive review of literature on students' awareness about biotechnology (namely Gunter, Kinderlerer, & Beyleveld, 1998; Cavanagh, Hood, & Wilkinson, 2004; Dawson, 2007; Klop & Severiens, 2007; Prokop et al., 2007). Items were formulated by considering relevant questions in published studies (Dawson, 2007; Dawson & Soames, 2006; Gaskell et al,. 2006; Miles, Ueland, & Frewer, 2005; Prokop et al., 2007) and adapting them according to the specificities of the student sample. Content and face validity were assessed through the scrutiny of two biology teachers, a microbiologist and a psychology researcher. Construct validity was assessed through a pilot study and the psychometric analysis of the pilot data, following the procedures described for the large-scale study (Fonseca, Costa, Lencastre, & Tavares, 2010). Part I of the questionnaire includes five socio-demographic questions. Part II is organised in six sections to assess knowledge, attitudes and interest about biotechnology, and the importance given to it. The *knowledge* section includes a multiple choice question, a list of options, and a True/False question (Fig. III.1) in which a *Don't know* option was included to reduce the social desirability bias (Black, 1999). The *attitudes* section was organised in three five-point Likert-type scales (Fig. III.1) according to the tripartite attitude model (Klop & Severiens, 2007; Rosenberg & Hovland, 1960). *Interest* was measured in a five-point Likert-type scale, and *importance* in a five-point Likert type item (Fig. III.1).

Procedure

Data were collected from January to April 2009. The questionnaire was administered in the students' native language, during class periods, without time restrictions, under the supervision of the teacher and/or the investigator. Using the SPSS version 17.0, the data collected were codified, recorded, cleansed and subjected to missing values analysis. Given that missing values were random and very limited (maximum score of 1.9%), the series mean method was used to replace them (Paul, Mason, McCaffrey, & Fox, 2008). Following descriptive analyses, the psychometric properties of the data were assessed through exploratory factor analysis (PCA with varimax rotation) and reliability analyses (Cronbach's coefficient alpha and Kuder Richardson formula 20 - KR-20, for ordinal and dichotomous variables respectively). Factor retention during EFA was decided based on the Kaiser criterion (eigenvalues greater than 1), the scree test, and meaningfulness of results according to the theoretical framework (Costello & Osborne, 2005; Hayton, Allen, & Scarpello, 2004). Upheld items were not freestanding, cross-loading or decreasing the scale's internal consistency, and displayed acceptable communalities (above 0.40), with loadings above 0.40 (Costello & Osborne, 2005; Sharma, 1996). The KMO measure of sampling adequacy and Bartlett's Test of Sphericity were used to assess the sample's suitability for EFA (Worthington & Whittaker, 2006).

Response frequencies were determined for each knowledge item, and a global knowledge score was computed (0-24 points) by combining the number of correct answers in questions Q3 (0-1 points), the number of biotechnology applications known (Q2; 0-8 points), and the selection of the most extensive definition of biotechnology (second option, Q1; 1

point). Mean responses were calculated for individual ordinal items, for the factors identified through EFA, for each scale and for the attitudes' section as a whole. The responses were examined and compared using Student's *t*-tests and ANOVA analysis. Size effect was measured using Cohen's *d*. Correlations between variables were assessed using Spearman's rank correlation coefficient.

PART I

Please indicate your: school; age; course; and gender.

PART II

Knowledge

Q1. *Biotechnology can be defined as a set of processes... (Select one option)*
(i)...in which recombinant DNA technology is used; (ii) ...applied to investigation and product development; (iii) ...which involves cell and tissue culture; (iv) ...through which genetically modified organisms (GMOs) can be developed

Q2. *Select the biotechnology application(s) you know.*
(i) Medicines and vaccines production; (ii) Hormone production; (iii) Production of organic products, such as milk or yogurt; (iv) Recovery of contaminated soils using GM bacteria; (v) Waste treatment; (vi) Production of insect and pesticide resistant plants; (vii) Utilization of plants with industrial purposes, namely the production of cosmetics, plastics and fuels; (viii) Amminoacids and vitamins production.

Q3. *Answer with True/False/Don't know.*
(a) All biotechnology applications are properly regulated; (b) The ingestion of GM foods can induce gene alterations; (c) There is evidence that GMOs can endanger the environment; (d) It is impossible to transfer genes from plants to animals; /..../ (m) GM cultures are sterile; (n) GM animals are bigger than the other animals; (o) Genetic manipulation techniques can allow to increase animal resistance to disease.

Importance

Q4. *How important do you think biotechnology is to the quality of life (1-Not at all important to 5-Very important)?*

Attitudes

Cognitive component

Q5. *Rate your approval towards the following activities (1-I do not approve it at all to 5-I approve it completely).*
(a) Use of yeast in the production of bread, wine and beer; (b) Use of yeast in animal food production; (c) Use of GM microorganisms in waste treatment; (d) Plant growth improvement in saline environments by gene alteration; (e) Treatment of genetic disorders by embryonic gene manipulation; (f) Treatment of genetic disorders by human gene manipulation; (g) Insertion of plant genes into animals; (h) Utilization of GM cows in the production of medicines for humans; (i) Production of pesticide resistant plants by gene manipulation; (j) Genetic modification of tomatoes to make them ripen more slowly and have a longer shelf life; (k) Use of insulin produced by bacteria; (l) Organ transplant from transgenic animals to humans; (m) Use of human cloning for therapeutic purposes

Affective component

Q6. *Rate your agreement with the following sentences (1-I totally disagree to 5-I totally agree).*
(a) It is our duty to authorize investigation that may lead to the development of more efficient medical treatments, even if it implies using embryonic stem cells; (b) The labels of transgenic foods should specify whether the food or any of its ingredients is genetically modified; (c) Future generations will benefit from biotechnology's medical applications; (a)[1] It is wrong to use embryonic stem cells in biomedical research, even if it may contribute to the development of medical treatments; (d) Each of us is capable of determining our intake of transgenic foods.

Behavioural component

Q7. *How often would you... (1-Never to 5-Always)* ...buy transgenic foods if they were easily available in supermarkets; (b) ...buy medicines obtained by genetic manipulation?

Q13. *How often would you... (1-Never to 5-Always)* (a) ...do a genetic test for medical diagnosis; (b) ...give the authorities access to your genetic information; (c)...buy transgenic foods if they were healthier than other foods; (d) ...buy transgenic foods if they were less expensive than other foods?

Interest

Q8. *Rate your interest towards biotechnology (1-I am not interested at all to 5-I am very interested).*

Q9. *How often do you... (1-Never to 5-Many times)* ...listen to news about biotechnology; (b) ...read articles or watch TV shows about biotechnology; (c) ...search the web for subjects related to biotechnology?

For simplification purposes, not all the items in question Q3 were displayed. Item Q6a[1], reverse to Q6a, was included as a control variable. The questionnaire also included three questions (Q10, Q11, and Q12) about the use students make of information sources to gather data to be used in a subsequent study, and an additional item to assess if the students considered the questionnaire interesting (Q14). The full version of the questionnaire is available from the authors upon request.

Fig. III.1. Schematic representation of the questionnaire used in the study.

Results

What do students know about biotechnology?

The KR-20 score for the knowledge section was 0.51. Since this is a minimum reliability estimate and the knowledge items are heterogeneous concerning their difficulty (Black, 1999; Guion & Highhouse, 2006), this score was considered sufficiently robust to uphold all items for analysis. None of the students answered correctly to all the items in this section and only 6% of them acknowledged the eight biotechnology applications listed (Q2, *M*=4.26, *SD*=1.80). Although 36% of the students were aware that biotechnology includes research and product development processes, 31% of them associated it with GMOs production. Students were mainly attentive of the most divulged applications. For instance, over 80% of them were acquainted with medicines and vaccines production, while, the recovery of polluted soils using GM bacteria was known by less than 35%.

The students answered correctly to approximately half of 15 items (M=7.61, *SD*=2.85) covering basic concepts and techniques (Q3, Fig. III.1). But the percentage of correct answers was significantly related with the students' academic profile (*F*(2,695)=62.55, *p*=0.00, *d*=0.85). Biology students answered a higher number of items correctly (*M*=9.05, *SD*=2.44), followed by non-biology students (*M*=7.74, *SD*=2.78), and non-S&T students (*M*=6.34, *SD*=2.65). Most of the respondents demonstrated adequate knowledge about applications such as the disease resistance enhancement of plants (96%, 80%, and 72% of the biology, non-biology and non-S&T students, respectively) and animals (95%, 79%, and 65% of the biology, non-biology and non-S&T students, respectively). Nevertheless, there were some situations revealing knowledge limitations. For example, 46%, 60%, and 71% of the biology, non-biology, and non-S&T students, respectively, believed that it is impossible to transfer genes from plants to animals. Moreover, 35%, 44%, and 45% of the biology, non-biology, and non-S&T students, respectively, believed that the ingestion of GM foods can induce gene alterations.

There were significant education-related differences in the global knowledge score (*F*(2,695)=50.61, *p*=0.00, *d*=0.76). The knowledge displayed by S&T students was less limited than the non-S&T students' (*M*=10.48, *SD*=3.47). And, as could be expected, biology students (*M*=13.58, *SD*=3.02) achieved higher scores than non-biology students (*M*=12.22, *SD*=3.54).

How do students feel about biotechnology?

The mean global attitudes score indicates that students hold in general positive attitudes (*M*=3.26, *SD*=0.55, *t*(697)=12.73, *p*=0.00, *d*=0.67), although this varies according to their academic profiles (*F*(2,695)=40.21, *p*=0.00). Following an identical pattern as the one obtained for knowledge, biology students (*M*=3.43, *SD*=0.49, *t*(209)=14.34, *p*=0.00 *d*=1.24) were more optimistic than non-biology students (*M*=3.29, *SD*=0.53, *t*(224)=8.18, *p*=0.00 *d*=0.77), and both of them shared more positive attitudes than non-S&T students (*M*=3.06, *SD*=0.53, *t*(262)=1.86, *p*=0.06 *d*=0.16).

Students' approval of biotechnology applications

EFA results for the scale *attitudes' cognitive component* reveal a three-factor structure accounting for 71.86% of the variance in the results, and measuring students' approval of *classical applications*, *animal manipulation*, and *gene therapy* (Fig. III.2). Items originally in the questionnaire that were excluded by this solution, were not considered for further analyses. Mean scores for the whole sample (Fig. III.2) indicate that students were optimistic about gene therapy and classical applications, but did not approve applications mentioning animal manipulation. As illustrated in Fig. III.2, there were significant education-related differences (*p*=0.00) evidencing a tendency for biology students to provide more positive responses than non-biology students and non-S&T students.

Students' feelings towards biotechnology

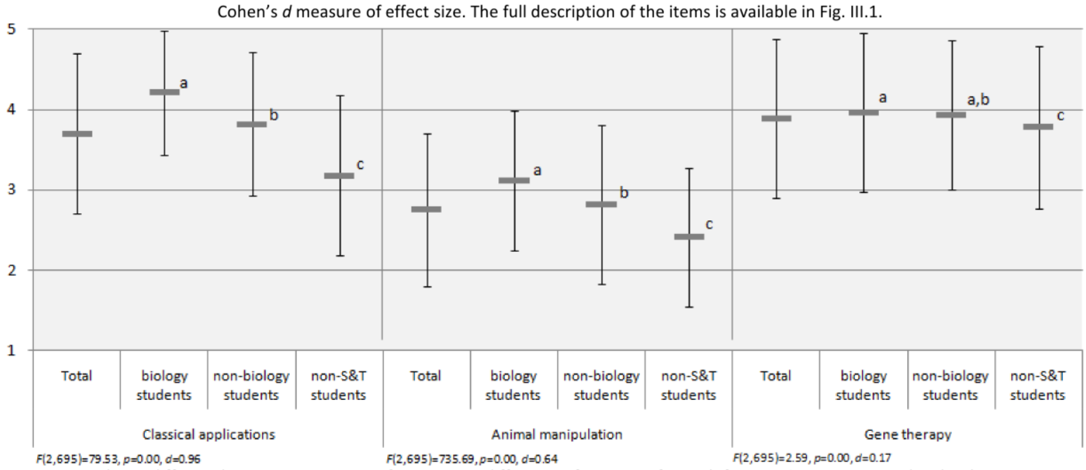
The KMO score for the scale *attitudes' affective component* is at the threshold (KMO=0.50), suggesting a disperse correlation pattern among the variables (Sharma, 1996). This denotes that the items' formulation renders this dimension unfit for factor analysis. Accordingly, students' affective response was assessed through the individual analysis of the items in question Q6 (Fig. III.1).

Concerning human embryo research (Q6a), biology (*M*=2.95, *SD*=1.21, *t*(209)=-0.63, *p*=0.53, *d*=0.06) and non-biology students (*M*=3.09, *SD*=1.27, *t*(224)=1.10, *p*=0.27, *d*=0.10) were indecisive about whether or not they agreed with this type of research, and non-S&T students considered that it should not be authorised (*M*=2.82, *SD*=1.21, *t*(262)=-2.40, *p*=0.02, *d*=0.21). Most of the students (*M*=4.05, *SD*=0.94, *t*(697)=29.45, *p*=0.00, *d*=1.58), agreed that future generations will benefit from advancements in biomedical applications. Students considered that GM food labelling is very important (*M*=4.69, *SD*=0.75, *t*(697)=59.77, *p*=0.00, *d*=3.19), and felt that they cannot control the amount of GM foods they ingest (*M*=2.81, *SD*=1.22, *t*(697)=-4.19, *p*=0.00, *d*=0.22). ANOVA results indicate significant education-related differences for items Q6b (*F*(2,695)=4.46, *p*=0.00, *d*=0.23), Q6c (*F*(2,695)=9.11, *p*=0.00, *d*=0.32), and Q6d (*F*(2,695)=7.50, *p*=0.00, *d*=0.29 pointing towards a more certain positioning of biology students.

Students' approval of biotechnology applications

Item	h^2	Identifiable Factors: *Classical applications*	*Animal manipulation*	*Gene therapy*	*M*	*SD*	*t*(697)	*p*	*d*
Q5a	0.78	0.87			3.91	1.14	21.09	0.00	1.13
Q5b	0.74	0.84			3.45	1.14	11.31	0.00	0.56
Q5g	0.64		0.80		2.70	1.10	-7.26	0.00	0.39
Q5h	0.68		0.80		2.71	1.22	-6.22	0.00	0.34
Q5l	0.56		0.71		2.84	1.30	-3.18	0.00	0.31
Q5E	0.82			0.90	3.77	1.20	17.05	0.00	0.91
Q5f	0.80			0.88	4.00	1.01	26.18	0.00	1.40
Eigenvalue		1.10	2.62	1.32					
% of variance		15.67	37.36	18.84					
Cronbach's alpha		0.70	0.69	0.75					
M		3.70	2.75	3.89					
SD		1.00	0.95	0.99					
t(697)		18.50	-6.91	23.60					
p		0.00	0.00	0.00					
d		0.99	0.37	1.27					

Exploratory factor analysis outcomes (*n*=698). Coefficients below 0.30 were suppressed. KMO=0.68. Bartlett's Test of Sphericity: χ^2(21)=1105.51, *p*=0.00. h^2 - communality coefficient. *M* - Mean. *SD* - Standard Deviation. One-sample *t*-test performed for test value=3. *d* - Cohen's *d* measure of effect size. The full description of the items is available in Fig. III.1.



a, b, c – different letters represent significant mean differences for α=0.05 for each factor. S&T – science and technology

Fig. III.2. Students' approval of biotechnology applications.

Students' behavioural intentions towards biotechnology

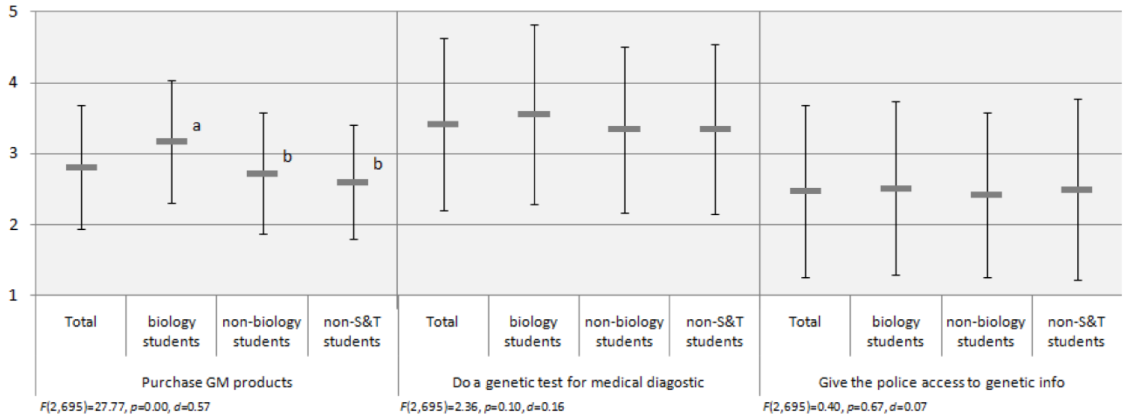
According to the EFA outcomes, the scale *attitudes' behavioural component* is consistent with a two-factor structure accounting for 62.48% of the total variance observed, and measuring the intention to *purchase GM products* and *allow access to one's genetic information* (Fig. III.3). However, the two items contributing to the latter factor were assessed individually, because the Cronbach's alpha value was at the threshold of acceptability (α=0.54). Item Q13c (Fig. III.1), which was excluded by EFA, was not upheld for analysis.

Regardless of their academic profile (p>0.05), students were willing to do genetic tests for medical diagnostic, but were unwilling to allow the authorities access to their genetic information (Fig. III.3). There were significant education-related differences in students' intention to purchase GM products (Fig. III.3). Unlike non-S&T students (M=2.60, SD=0.80, t(262)=-8.04, p=0.00, d=0.71) and non-biology students (M=2.72, SD=0.86, t(224)=-4.85, p=0.00, d=0.46) who were not interested,, biology students reported that they would buy these products (M=3.16, SD=0.86, t(697)=2.74, p=0.01, d=0.26).

Students' behavioural intentions towards biotechnology

Item	h^2	Identifiable Factors: *Purchase GM products*	Identifiable Factors: *Allow access to genetic information*	*M*	*SD*	t(697)	*p*	*d*
Q7a	0.76	0.87		2.83	1.02	-4.49	0.00	0.24
Q7b	0.67	0.81		3.02	1.04	0.57	0.57	0.03
Q13d	0.51	0.67		2.58	1.23	-9.04	0.00	0.48
Q13a	0.65		0.83	3.41	1.22	8.91	0.00	0.48
Q13b	0.70		0.79	2.47	1.22	-11.38	0.00	0.61
Eigenvalue		2.16	1.13					
% of variance		43.12	22.55					
Cronbach's alpha		0.70	0.54					
M		2.81						
SD		0.87						
t(697)		-5.79						
p		0.00						
d		0.31						

Exploratory factor analysis outcomes (n=698). Coefficients below 0.30 were suppressed. KMO=0.66. Bartlett's Test of Sphericity: $\chi^2(10)$=600.95, p=0.00. h^2 - communality coefficient. M - Mean. SD - Standard Deviation. One-sample t-test performed for test value=3. d - Cohen's d measure of effect size. The full description of the items is available in Fig. III.1.



a, b, c – different letters represent significant mean differences for α=0.05 for each factor. S&T – science and technology

Fig. III.3. Students' behavioural intentions towards biotechnology.

What do students think about biotechnology?

EFA and reliability analyses for the *interest* scale reveal a unifactor solution (KMO=0.76, $\chi^2(6)$=928.50, *p*=0.00), with adequate reliability (α=0.81). The mean *interest* score indicates that students were not interested in biotechnology (*M*=2.70, *SD*=0.87, *t*(697)=-9.24, *p*=0.00, *d*=0.49), although there were significant education-related differences in this regard (*F*(2.695)=91.74, *p*=0.00, *d*=1.03). Non-S&T students were the least interested (*M*=2.25, *SD*=0.76, *t*(262)=-16.06, *p*=0.00, *d*=1.40), followed by non-biology students (*M*=2.73, *SD*=0.82, *t*(224)=-5.03, *p*=0.00, *d*=0.47). Nevertheless, biology students showed interest in biotechnology (*M*=3.22, *SD*=0.75, *t*(209)=4.26, *p*=0.00, *d*=0.41).

Contrasting with these low interest levels, students agreed on the importance of biotechnology for the improvement of the quality of life (*M*=3.79, *SD*=0.82, *t*(697)=25.40, *p*=0.00, *d*=1.36). The pattern of differences for the three academic profile-based groups (*F*(2,695)= 43.16, *p*=0.00, *d*=0.71) match the ones observed for the interest: biology students attributed more importance to biotechnology (*M*=4.15, *SD*=0.64, *t*(209)=25.98, *p*=0.00, *d*=2.54), than non-biology students (*M*=3.81, *SD*=0.86, *t*(224)=14.18, *p*=0.00, *d*=1.33), and non-S&T students (*M*=3.48, *SD*=0.80, *t*(262)=9.81, *p*=0.00, *d*=0.85).

How do knowledge, attitudes, interest and importance influence students' perceptions about biotechnology?

Students' knowledge was positively correlated with their attitudes globally (r_s=0.38, *n*=698, *p*=0.00), and according to cognitive (r_s=0.38, *n*=698, *p*=0.00), affective (r_s=0.21, *n*=698, *p*=0.00) and behavioural (r_s=0.25, *n*=698, *p*=0.00) dimensions. Nevertheless, students' behavioural intentions were more strongly correlated with their cognitive appraisal of biotechnology (r_s=0.45, *n*=698, *p*=0.00) than with knowledge.

Knowledge was also positively correlated with interest (*r*=0.43, *n*=698, *p*=0.00) and importance (*r*=0.29, *n*=698, *p*=0.00), and these dimensions were correlated with each other (*r*=0.46, *n*=698, *p*=0.00). Furthermore, students' attitudes were positively correlated with interest (r_s=0.33, *n*=698, *p*=0.00) and importance (r_s=0.35, *n*=698, *p*=0.00) as well. These correlation patterns were sustained within each of the three academic profile-based groups (see Appendix III.A1).

How does gender affect students' perceptions about biotechnology?

There were no significant differences between male and female students' knowledge ($t(696)=0.88$, $p=0.38$, $d=0.07$). Furthermore, females were as interested ($t(696)=0.05$, $p=0.96$, $d=0.00$), and attributed as much importance ($t(696)=0.63$, $p=0.53$, $d=0.05$) as males to biotechnology. However, males ($M=3.34$, $SD=0.53$, $t(330)=12.84$, $p=0.00$, $d=0.91$) demonstrated more positive attitudes ($t(696)=-2.86$, $p=0.00$, $d=0.22$) than females ($M=3.27$, $SD=0.47$, $t(366)=10.89$, $p=0.00$, $d=0.81$) globally and according to cognitive ($t(696)=-3.12$, $p=0.00$, $d=0.24$) and affective ($t(664.15)=-3.02$, $p=0.00$, $d=0.23$) appraisals. Nevertheless, both genders' behavioural intentions did not differ significantly ($t(696)=-0.55$, $p=0.59$, $d=0.04$). This global pattern of correlations is consistent with the results obtained for biology students. For non-biology students and non-S&T students there were no significant gender-associated differences ($p>0.05$).

Discussion

Students associated biotechnology with modern procedures, and were more attentive of biomedical applications with obvious social impacts, overlooking less divulged applications. In addition, the inconsistencies in their answers suggest a superficial knowledge of biotechnology processes. In fact, similarly to student populations in other countries (Dawson, 2007; Uşak et al., 2009), Portuguese students' understanding of basic notions and fundamental processes was shown to be inaccurate. The data further add that even biology students had misconceptions, even though they were more knowledgeable than non-S&T students. This indicates that educational measures are required to promote sounder and more thorough understandings of biotechnology concepts and techniques among non-S&T students and biology students, which can include curricular re-structuring. The Portuguese 12th grade biology curriculum is structured upon a biotechnological perspective of molecular biology and genetics topics (DGIDC, 2004). It is possible that the demanding nature of the notions addressed confuses students about complex biotechnology issues, as suggested by Falk et al. (2008).

Students' attitudes towards biotechnology have been known to differ depending on factors such as the object and the usefulness of the manipulation (Dawson, 2007; Klop & Severiens, 2007; Sáez et al., 2008). In this study, students' responses were predominantly influenced by the purpose and usefulness of the application, as demonstrated for instance by the fact that students were willing to give access to their genetic information for medical purposes, but not when public security was concerned. This is not surprising considering that biomedical applications tend to be viewed favourably (Klop & Severiens, 2007; Sáez et al., 2008), whereas the societal uses of genetic information raise public concerns (Gaskell et al., 2006). The students were noticeably receptive to gene therapy and did not outright disapprove human embryo research, which may result from the perception that the benefits associated with this type of research outweigh the risks, as previously reported (The Gallup Organization, 2009). However, this contrasts with prior findings for adult populations from Portugal and other European countries, such as Slovenia, Estonia, Malta, and Ireland, who generally disagree with stem cell research, particularly when human embryonic cells are involved (Gaskell et al., 2006). Regardless of the context, animal manipulation was highly disapproved by the majority of the students. To some extent, this is line with studies demonstrating that applications mentioning the manipulation of animals are usually considered less acceptable than applications involving the use of microorganisms and plants (Dawson & Schibeci, 2003; Einsiedel, 2005).

This study confirms that students value labelling information about GM food, a common feeling among student populations from different countries (Klop & Severiens, 2007; Lamanauskas & Makarskaitė-Petkevičienė, 2008; Prokop et al., 2007; Uşak et al., 2009). Nevertheless, the participants were uncertain about their capacity to determine the amount of dietary GM foods, which further adds that they may perceive label information as scarce and/or insufficiently reliable to allow this control.

Students' attitudes are impacted by their academic profile. Biology students were the most favourable about biotechnology, followed by non-biology students and non-S&T students. In fact, in line with previous studies (Prokop et al., 2007; Sturgis et al., 2005), knowledge and attitudes were positively correlated. Students displaying higher levels of knowledge also demonstrated more positive attitudes towards biotechnology, as evidenced by the consistency between the knowledge and attitudinal patterns for the three academic profile-based student groups. Furthermore, knowledge was positively correlated with cognitive, affective and behavioural attitudinal dimensions. Most importantly, students' behavioural intentions also depended on affective responses and were more strongly associated with cognitive elements than with knowledge itself. This reinforces the assumption that attitudes towards biotechnology are coined upon the integrated articulation of cognitive, affective and behavioural features (Klop & Severiens, 2007). These findings emphasise the acceptance of biotechnology applications as a concept resulting from an interactive network of diverse attitudinal factors that mediate the expression of knowledge (Amin et al., 2007; Costa-Font, Gil, & Traill, 2008; Klerck & Sweeney, 2007; Sáez et al., 2008).

With the exception of biology students, the participants were not interested in biotechnology, which corroborates the findings of the recent EB (Flash EB Series No239) survey (The Gallup Organization, 2009). Nevertheless, students acknowledged the importance of biotechnology. According to Ryan & Deci's (2000) argument, interest and importance are respectively, endogenous and exogenous determinants of motivational responses. In this study, these two dimensions were positively correlated with each other and with knowledge and attitudes, supporting the existence of a link between students' motivation to learn about biotechnology and their knowledge and attitudes towards the subject. This implies that science education interventions must be prepared based on biotechnology issues that students perceive as meaningful and feel stimulated to understand.

Women have been described as less interested in S&T topics than men (Hagelin 2004; Sjøberg & Schreiner 2006), which is thought to be the reason why they seem to be less knowledgeable and attentive about biotechnology (Gaskell et al., 2006; Hagelin, 2004; Moerbeek & Casimir, 2005). Contrasting with these findings (Prokop et al., 2007), there were no significant gender-related differences concerning students' levels of knowledge, interest, and importance attributed. Actually, the only significant differences occurred for the biology students' attitudes. Males tended to be more optimistic than females, suggesting that gender significance in this regard depends on the individuals' academic profile. In addition, considering that students' intention to purchase GM products was not gender-affected, the results do not entirely support the gender paradox previously described by Moerbeek & Casimir (2005) for consumer acceptance of GM food.

Conclusions and Implications

This work demonstrates that students' perceptions are shaped by complex interactions between cognitive, motivational and attitudinal elements. In spite of a tendency for biology students to be more knowledgeable, optimistic and motivated towards this issue, the intertwining network of factors that lead to opinion formation, attitudinal development and, ultimately, behavioural intention, seemed to operate regardless of the inevitable discrete gender and education specificities.

The findings suggest the need for corrective educational measures. Several authors have discussed the quality of science curricula, associating their unadjusted coverage of classic genetics and hereditary contents with the failure to promote proper understandings of biotechnology notions and procedures (Lamanauskas & Makarskaitė-Petkevičienė, 2008; Prokop et al., 2007; Uşak et al., 2009). Currently, the Portuguese 12th grade biology curriculum incorporates modern molecular biology and biotechnology contents, with a predominant focus on their mobilisation into concrete everyday situations (DGIDC, 2004). Interestingly, even the students engaged with this curriculum displayed misconceptions about fundamental concepts and principles, suggesting that adjustments are required to increase its efficiency. Considering that students' opinions and intended behaviours were shown to be mainly determined by personal cognitive and affective factors, the integration of biotechnology in science curricula must articulate innovative concepts and strategies with the discussion of social and environmental consequences of biotechnology. Teaching programmes must enable students to overcome the usually controversial approaches of biotechnology advantages and risks, and justify their decisions on balanced appraisals of its benefits and limitations. The indicators gathered in this study were applied to the development of a set of practical activities (Fonseca & Tavares, 2011a,b) that are being validated in 12th grade classes. These measures must also be extended to non-S&T students, namely through the promotion of debates, the discussion of dilemmas, and the analysis of media news.

Finally, this study informs future research on students' perceptions about biotechnology and other socio-scientific issues, by demonstrating that motivational elements must be considered together with attitudinal dimensions in the analysis of how knowledge is transferred into the development of opinions and perceptions. Applying this framework to focused case-study-based research projects will allow the in-depth examination of specific topics. Since teacher practice is determining to students' learning, it would be important to assess the relationships between students' and their teachers' perceptions under a multidimensional approach.

Acknowledgements

The authors are grateful to Catarina L. Santos for careful reading of the manuscript and helpful comments and suggestions and to all the participant students. MJF is supported by the FCT fellowship SFRH/BD/37389/2007.

References

Amin, L., Jahi, J., Nor, A. R., Osman, M., & Mahadi, N. M. (2007). Public acceptance of modern biotechnology. *Asia Pacific Journal of Molecular Biology and Biotechnology*, *15*(2), 39-51.

Black, T.R. (1999). *Doing quantitative research in the social sciences. An integrated approach to research design, measurement and statistics*. London: SAGE Publications.

Cavanagh, H., Hood, J., & Wilkinson, J. (2004). Riverina high school students' views of biotechnology. *Electronic Journal of Biotechnology*, *8*(2), 1-7.

Costa-Font, M., Gil, J., & Traill, W. B. (2008). Consumer acceptance, valuation of and attitudes towards genetically modified food: Review and implications for food policy. *Food Policy*, *33*(2), 99-111.

Costello, A.B., & Osborne, J. W. (2005). Best practices in exploratory factor analysis: Four recommendations for getting the most from your analysis. *Practical Assessment, Research and Evaluation*, *10*(7). Retrieved from http://pareonline.net/getvn.asp?v=10&n=7

Dawson, V. (2007). An Exploration of high school (12–17 Year Old) students' understandings of, and attitudes towards biotechnology processes. *Research in Science Education*, *37*(1), 59-73.

Dawson, V., & R. Schibeci. (2003). Western Australian school students' understanding of biotechnology. *International Journal of Science Education*, *25*(1), 57-69.

Dawson, V., & Soames, C. (2006). The effect of biotechnology education on Australian high school students' understandings and attitudes about biotechnology processes. *Research in Science & Technological Education*, *24*(2), 183-198.

Direcção-Geral de Inovação e de Desenvolvimento Curricular. (2004). *Programa de Biologia 12º ano. Curso Científico-Humanístico de Ciências e Tecnologias.* Lisbon: Ministério da Educação.

Education, Audiovisual and Culture Executive Agency**. (**2009). *Key Data on Education in Europe*. Brussels: European Comission.

Einsiedel, E.F. (2005). Public perceptions of transgenic animals. *Revue Scientifique et Technique-Office International Des Epizooties*, *24*(1), 149-157.

Falk, H., Brill, G., & Yarden, A. (2008). Teaching a biotechnology curriculum based on adapted primary literature. *International Journal of Science Education*, *30*(14), 1841-1866.

Fonseca, M. J., Costa, P., Lencastre, L., & Tavares, F. (2010). Assessing assessment tools: towards questionnaire improvement through validation. In G. Cakmakci & M.F. Taşar (Eds.). *Contemporary science education research: learning and assessment* (pp. 259-266). Ankara: Pegem Akademi.

Fonseca, M. J., & Tavares, F. (2011a). Natural antibiotics: a hands-on activity on garlic's antibiotic properties. *American Biology Teacher*, *73*(6), 342-346.

Fonseca, M. J., & Tavares, F. (2011b). The bactericidal effect of sunlight. *American Biology Teacher*, *73*(9), 548-552.

Gaskell, G., Stares, S., Allansdottir, A., Allum, A., Corchero, C., Fischler, C., …Wagner, W. 2006. *Europeans and biotechnology in 2005: Patterns and trends. Final report on Eurobarometer 64.3*. Brussels: European Commission: Research Directorate-General

Guion, R.M., & S. Highhouse. (2006). *Essentials of Personnel Assessment and Selection*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Gunter, B., Kinderlerer, J., & Beyleveld, D. (1998). Teenagers and biotechnology: A survey of understanding and opinion in Britain. *Studies in Science Education*, *32*(1), 81-112.

Hagelin, J. (2004). Public opinion surveys about xenotransplantation. *Xenotransplantation*, *11*(6), 551-558.

Hanegan, N., & Bigler, A. (2009). Infusing authentic inquiry into biotechnology. *Journal of Science Education and Technology*, *18*(5), 393-401.

Harms, U. (2002). Biotechnology education in schools. *Electronic Journal of Biotechnology*, *5*(3), 205-211.

Hayton, J.C., Allen, D. G., & Scarpello, V. (2004). Factor retention decisions in exploratory factor analysis: a tutorial on parallel analysis. *Organizational Research Methods*, *7*(2), 191-205.

Kidman, G. (2008). Asking students: What key ideas would make classroom biology interesting? *Teaching Science*, *54*(2), 34-38.

Klerck, D., & Sweeney, J. C. (2007). The effect of knowledge types on consumer-perceived risk and adoption of genetically modified foods. *Psychology & Marketing*, *24*(2), 171-193.

Klop, T., & Severiens, S. (2007). An exploration of attitudes towards modern biotechnology: A study among Dutch secondary school students. *International Journal of Science Education*, *29*(5), 663-679.

Lamanauskas, V., & Makarskaitė-Petkevičienė, R. (2008). Lithuanian university students' knowledge of biotechnology and their attitudes to the taught subject. *Eurasia Journal of Mathematics, Science & Technology Education*, *4*(3), 269-277.

Miles, S., Ueland, Ø., & Frewer, L. J. (2005). Public attitudes towards genetically-modified food. *British Food Journal*, *107*, 246-262.

Milne, C., & Morrison, A. (2007). Demystifying biotechnology: The PCR Game. *Teaching Science*, *53*(1), 19-23.

Moerbeek, H., & Casimir, G. (2005). Gender differences in consumers' acceptance of genetically modified foods. *International Journal of Consumer Studies*, *29*(4), 308-318.

Paul, C., Mason, W., McCaffrey, D., & Fox, S. (2008). A cautionary case study of approaches to the treatment of missing data. *Statistical Methods and Applications*, *17*(3), 351-372.

Pin, R.R., & Gutteling, J. M. (2009). The development of public perception research in the genomics field. An empirical analysis of the literature in the field. *Science Communication*, *31*(1), 57-83.

Prokop, P., Lesková, A., Kubiatko, M., & Diran, C. (2007). Slovakian students' knowledge of and attitudes toward biotechnology. *International Journal of Science Education*, *29*(7), 895-907.

Rosenberg, M. J., & Hovland, C. I. (1960). Cognitive, affective, and behavioral components of attitudes. In C.I. Hovland, & M.J. Rosenberg (Eds.), *Attitude organization and change: An analysis of consistency among attitude components* (pp. 1-14). New Haven, CT: Yale University Press.

Rothhaar, R., Pittendrigh, B. R., & Orvis, K. S. (2006). The Lego® analogy model for teaching gene sequencing and biotechnology. *Journal of Biological Education*, *40*(4), 166-71.

Ryan, R. M., & Deci, E. L. (2000). Intrinsic and extrinsic motivations: Classic definitions and new directions. *Contemporary Educational Psychology*, *25*(1), 54-67.

Sáez, M. J., Niño, A. G., & Carretero, A. (2008). Matching society values: Students' views of biotechnology. *International Journal of Science Education*, *30*(2), 167-183.

Sharma, S. (1996). *Applied multivariate techniques*. New York: Jonh Wiley & Sons, Inc.

Sjøberg, S., & C. Schreiner. 2006. How do students perceive science and technology? *Science in School*, 1, 66-69.

Steele, F., & Aubusson, P. (2004). The challenge in teaching biotechnology. *Research in Science Education*, *34*, 365-387.

Sturgis, P., Cooper, H., & Fife-schaw, C. (2005). Attitudes to biotechnology: Estimating the opinions of a better-informed public. *New Genetics & Society*, *24*, 31-56.

The Gallup Organization. (2009). *Young people and science. Analytical report. Flash Eurobarometer 239*. Brussels: European Commission, Research Directorate-General.

Uşak, M., Erdogan, M., Prokop, P., & Özel, M. (2009). High school and university students' knowledge and attitudes regarding biotechnology. *Biochemistry and Molecular Biology Education*, *37*(2), 123-130.

Verdume, A., & Viaene, J. (2003). Exploring and modelling consumer attitudes towards genetically modified food. *Qualitative Market Research: An International Journal*, *6*(2), 95-110.

Worthington, R.L., & Whittaker, Y. A. (2006). Scale development research: A content analysis and recommendations for best practices. *The Counseling Psychologist*, *34*(6), 806-838.

Appendix III.A1

Academic profile-based correlation patterns between students' attitudes towards, interest about and importance attributed to biotechnology

		Knowledge (total score)	Attitudes (total score)	Attitudes' cognitive component	Attitudes' affective component	Attitudes' behavioural component	Interest	Importance
non-S&T students	Knowledge (total score)	1.00	0.28**	0.23**	0.34**	0.15*	0.24**	0.19**
	Attitudes (total score)	0.28**	1.00	0.83**	0.64**	0.77**	0.15*	0.26**
	Attitudes' cognitive component	0.23**	0.83**	1.00	0.34**	0.40**	0.12	0.23**
	Attitudes' affective component	0.34**	0.64**	0.34**	1.00	0.41**	0.11	0.16*
	Attitudes' behavioural component	0.15*	0.77**	0.40**	0.41**	1.00	0.13*	0.23**
	Interest	0.24**	0.15	0.12	0.11	0.13*	1.00	0.37**
	Importance	0.19**	0.26**	0.23**	0.16*	0.23**	0.37**	1.00
non-biology students	Knowledge (total score)	1.00	0.27**	0.24**	0.13	0.25**	0.39**	0.22*
	Attitudes (total score)	0.27**	1.00	0.88**	0.64**	0.73**	0.30**	0.31**
	Attitudes' cognitive component	0.24**	0.88**	1.00	0.45**	0.44**	0.23**	0.24**
	Attitudes' affective component	0.13	0.64**	0.45**	1.00	0.31**	0.26**	0.26**
	Attitudes' behavioural component	0.25**	0.73**	0.44**	0.31**	1.00	0.27**	0.28**
	Interest	0.39**	0.30**	0.23**	0.26**	0.27**	1.00	0.44**
	Importance	0.22**	0.31**	0.24**	0.26**	0.28**	0.44**	1.00
biology students	Knowledge (total score)	1.00	0.32**	0.37**	0.09	0.20**	0.32**	0.15*
	Attitudes (total score)	0.32**	1.00	0.86**	0.60**	0.73**	0.22**	0.19*
	Attitudes' cognitive component	0.37**	0.86**	1.00	0.41**	0.41**	0.13	0.11
	Attitudes' affective component	0.09	0.60**	0.41**	1.00	0.19**	0.05	0.15*
	Attitudes' behavioural component	0.20**	0.73**	0.41**	0.19**	1.00	0.30**	0.17*
	Interest	0.32**	0.22**	0.13	0.05	0.30**	1.00	0.25**
	Importance	0.15*	0.19*	0.11	0.15*	0.17*	0.25**	1.00

Spearman's rank correlation coefficient. * indicates significant differences for α=0.05. ** indicates significant differences for α=0.01.

CHAPTER IV

Disclosing biology teachers' beliefs about biotechnology and biotechnology education

Fonseca, M. J., Costa, P., Lencastre, L., & Tavares, F.
Teaching and Teacher Education 2012
28(3), 368-381

Chapter IV

Disclosing biology teachers' beliefs about biotechnology and biotechnology education

Abstract

Teachers have been shown to frequently avoid addressing biotechnology topics. Aiming to understand the extent to which teachers' scarce engagement in biotechnology teaching is influenced by their beliefs and/or by extrinsic constraints, such as practical limitations, this study evaluates biology teachers' beliefs about biotechnology and biotechnology teaching. The findings of a survey administered to 93 secondary school teachers reveal that, in spite of holding positive beliefs about biotechnology, teachers overestimate the obstacles presented at biotechnology teaching, particularly concerning material and resource limitations. Implications of these findings for teacher training program design are discussed.

Introduction

Science education researchers and practitioners' endeavour to promote scientific literacy is underpinned by the acknowledgement that the ability to make informed decisions about socio-scientific issues is essential for an active and balanced citizenship (Bryce & Gray, 2004; Cabo Hernández, Enrique Mirón, & Cortiñas Jurado, 2006).

The need to adapt science curricula and instructional practices according to the socio-economic changes introduced by recent scientific and technological advances has led to the development of STS and SSI educational approaches (Bennett, Lubben, & Hogarth, 2007; Zeidler, Sadler, Simmons, & Howes, 2005). These curricular formats are structured upon the trans- and interdisciplinary articulation of the social and environmental repercussions of science and technology, with the aim of eliciting scientifically sustained understandings (Bennett et al., 2007; Bryce & Gray, 2004; Zeidler et al., 2005). Among the subjects that have been explored through these approaches, biotechnology has been given particular attention (Hanegan & Bigler, 2009; Steele & Aubusson, 2004). Biotechnology's rapid development has contributed to important biomedical, agricultural and industrial breakthroughs. However, in spite of its potential, biotechnology continuously challenges the public by raising many controversial issues (Hanegan & Bigler, 2009). With the pervasive biased and contentious views about issues such as human cloning, or the production of GM organisms provided by the media, schools and specifically teachers, are asked to play a vital role in the promotion of biotechnology education (Bryce & Gray, 2004; Hanegan & Bigler, 2009; Steele & Aubusson, 2004). Accordingly, in recent years, biotechnology-related topics have been increasingly incorporated in secondary science curricula in numerous countries (Hanegan & Bigler, 2009; Steele & Aubusson, 2004). In addition, several networks and organisations, such as the European Initiative for Biotechnology Education (http://www.eibe.info/) or the National Centre for Biotechnology Education (http://www.ncbe.reading.ac.uk/), have been producing a wealth of educational resources. Nevertheless, in spite of this investment in biotechnology education, studies conducted in countries such as Scotland, Spain, and New Zealand, have shown that teachers tend to avoid teaching biotechnology-related topics and base their decision on reasons such as the insufficiency of resources for experimental activities and the inadequacy of their academic training (Bryce & Gray, 2004; Cabo Hernández et al., 2006; Steele & Aubusson, 2004).

Besides these extrinsic handicaps, an important aspect to keep in mind when considering teachers' limited engagement in biotechnology teaching stems from the nature of the contents to be addressed and the recommended strategies to do so. To some extent, the features of biotechnology-related contents swerve from the traditional factual and objective science subjects with which most teachers are acquainted (Akerson, Morrison, & McDuffie, 2006; Bryce & Gray, 2004). Moreover, authentic inquiry-driven biotechnology curricula, which have been reported to efficiently promote scientific literacy (Hanegan & Bigler, 2009) have also been shown to be demanding for teachers (Falk, Brill, & Yarden, 2008; Wallace & Kang, 2004). Since teacher practice is influenced by content and pedagogical knowledge, and by teachers' beliefs about the subject matter and their own teaching practices (Falk et al., 2008; Siti Hendon & Khalijah, 2007; Van Driel, Beijaard, & Verloop, 2001), it is necessary to understand teachers' beliefs about biotechnology education and biotechnology itself. Unveiling these elements is essential to determine if teachers engagement in biotechnology education is compromised by external factors related with the school's functioning and equipment, among others, or most importantly, by their familiarity and interest about the subject. This is of particular importance given the limited research on this topic. In fact, in spite of several worldwide studies assessing students' awareness and attitudes towards biotechnology (Dawson, 2007; Sáez, Niño, & Carretero, 2008; Usak, Erdogan, Prokop, & Ozel, 2009), and a few comparing students and teachers perceptions (Kidman, 2009; Steele & Aubusson, 2004), only a limited number has specifically addressed science teachers' perceptions about biotechnology (Bryce & Gray, 2004; Cabo Hernández et al., 2006; Šorgo & Ambrožič-Dolinšek, 2010).

In this context, the present study intends to disclose secondary biology teachers' beliefs about biotechnology and biotechnology education and understand how they perceive the challenges it presents. By cross-examining the importance teachers give to different elements that impact teaching, ranging from material limitations to conceptual, motivational and attitudinal constraints, this work explores the existence of a differential contribution of exogenous and endogenous factors that modulate teachers' decisions regarding biotechnology education. The framework underlying this investigation considers that teachers' engagement in biotechnology teaching is affected by their beliefs about biotechnology itself and biotechnology education, as well as by practical limitations that impinge their practice. Whereas several of these practical constraints, including the ones already mentioned, are described in the literature (Bryce & Gray, 2004; Cabo Hernández et al., 2006; Steele & Aubusson, 2004), the scarcity of research focusing specifically on teachers' beliefs about biotechnology and biotechnology education demands the contextualisation of the study in relation to previous studies on teachers' subject matter beliefs in general.

Previous research on the relationship between teachers' subject matter beliefs and practice

Nature of teachers' educational beliefs

Through the years, the complex nature of teachers' beliefs has been the topic of numerous research articles, which often share contrasting perspectives about the definition, distinctiveness and influence of knowledge and beliefs (Gess-Newsome, 1999; Nespor, 1985). In fact, the definition of beliefs has been widely discussed in the literature, although there is general agreement that beliefs are dynamic cognitive representations comprised of premises and propositions that may not be logically structured, but that are felt to be true and guide a person's actions (Richardson, 2003). The boundaries between beliefs and other constructs such as attitudes, values and perceptions are often manifestly thin (Richardson, 2003), and one of the major concerns for researchers is the distinction between beliefs and knowledge. Nevertheless, whereas knowledge is usually described as rational, evidential and dynamic, beliefs are characterised as both evidential and non-evidential, episodic, and encompassing affective and evaluative functions (Gess-Newsome, 1999; Nespor, 1985). Teachers seem to rely on their core belief systems rather than on knowledge to make instructional decisions to answer particular events of educational environments (Nespor, 1985; Wallace & Kang, 2004). Because beliefs are regarded as reliable predictors of behaviour (Gess-Newsome, 1999), it has been argued that teachers' classroom actions are implicitly comprised in their beliefs and should be considered within the complexity of belief systems as a whole (Wallace & Kang, 2004). Considering the rapid pace of biotechnological development and the complexity of its implications, it is necessary to understand how teachers' beliefs about biotechnology influence their teaching practices, which depends primarily on the characterisation of those beliefs.

Development and evolution of teachers' educational beliefs

Another important feature of teachers' educational beliefs concerns their development and evolution. Teacher beliefs about education are developed at an early stage during the teachers' own education years, so these are usually already established when they enter their teacher education program (Nespor, 1985; Özgün-Koca & Ilhan Sen, 2006; Van Driel, Bulte, & Verloop, 2007). In spite of this rigidity, teachers' prior beliefs continue to be shaped during their practicing years (Gess-Newsome, 1999; Özgün-Koca & Ilhan Sen, 2006). Experience foils the structuring of novice teachers' beliefs and perceptions into coherently interwoven conceptual frameworks in which newly developed knowledge is integrated (Gess-Newsome, 1999; Özgün-Koca & Ilhan Sen, 2006; Van Driel et al., 2007). However, experienced teachers may adopt identical behaviours as those of novices when asked to address contents outside their area of expertise (Sanders, Borko, & Lockard, 1993). Contrasting with traditional disciplines such as microbiology or cellular biology, biotechnology has a markedly multidisciplinary character. Furthermore, considering the often contentious and ethically charged nature of some biotechnology issues, the teaching is inevitably different from that of other, less controversial science subjects (Bryce & Gray, 2004). As this represents the need for teachers to make choices according to demands that are relatively new to science teaching, the assessment of teachers' beliefs about biotechnology education provides relevant baseline data to increase its effectiveness.

The impact of teachers' educational beliefs on their practice

Teachers' educational beliefs are assumed to be interconnected and to act as filters through which innovative instructional practices, curricular projects, and contents are assessed, selected and implemented (Nespor, 1985; Pajares, 1992; Wallace & Kang, 2004). While the importance of appraising the interactions between different beliefs is largely acknowledged, it is also important to be aware that people can hold contrasting beliefs about closely related issues (Van Driel et al., 2007). However, so far, research has mainly focused on teachers' general educational beliefs (Nespor, 1985; Pajares, 1992), and the studies addressing domain specific beliefs are limited, particularly when biotechnology is considered (Kidman, 2009). Nevertheless, it is known that teachers' orientation towards particular domains affects their choices about which topics to teach and how to teach them (Van Driel et al., 2007). Understanding teachers' beliefs about biotechnology and biotechnology education is required to determine how, and to what extent, teachers' beliefs about biotechnology modulate their decision to invest in biotechnology education is important, as teachers are in the frontline to foster their students' literacy towards this socio-scientific issue.

Purpose of the study

This study, set up in Portugal, examines secondary biology teachers' beliefs about biotechnology education by assessing the relationship between their beliefs about biotechnology and biotechnology teaching. This investigation was conceived to characterise teachers' receptivity to biotechnology education, aiming to diagnose the main constraints that can determine their engagement in teaching biotechnology-related topics. Drawing on the framework outlined in the introductory section, the study follows the major goal of distinguishing between: i) the influence of teachers' beliefs about biotechnology and biotechnology education, i.e. endogenous elements that affect their practice; and; ii) the impact of exogenous elements that also affect teaching, such as material, resource, and schedule limitations. This understanding can foster improved teacher practice, namely by allowing to outline guidelines for the design of focused teacher training programs and to boost science education policy re-structuring. This is of paramount importance both in Portugal, and in other countries that have also incorporated biotechnology education into their science curricula, such as Australia, New Zealand, the UK, and the USA (Hanegan & Bigler, 2009; Steele & Aubusson, 2004), or that are planning to do so. For this purpose, the main research question driving this study was: to what extent do teachers' beliefs about biotechnology education impinge on their willingness to invest in it? To answer it, the following questions were formulated:

- To which factors do teachers attribute more importance in limiting their teaching of biotechnology-related issues?

- Do teachers' beliefs towards biotechnology influence their beliefs about biotechnology education?
- Are endogenous limitations associated with teachers' beliefs more determinant than exogenous factors, such as the unavailability of materials or the lack of time to prepare classes?
- Do teachers' beliefs about biotechnology education vary according to their general profile regarding age, instructional experience, and qualifications?

Method

This study follows a quantitative assessment approach based on an inquiry survey through questionnaire implementation.

Participants

The participants were inservice secondary biology teachers. Biology teachers were considered eligible to participate because they are professionally qualified to teach biotechnology at secondary school. According to the Portuguese Ministry of Education, biotechnology-related topics are predominantly emphasised and must be specifically addressed in the 12th grade (student age 17-18 years) biology curriculum, which focuses on molecular biology, genetics and genomics issues under a biotechnological perspective (DGIDC, 2004). Given that these topics are determined by curricular standards, Portuguese teachers are not called to choose which topics to teach, but only the instructional designs used and the extensiveness of the discussions promoted. Ever since the introduction of the Bologna Process in 2005-2009, prospective biology teachers must receive three years of biology and/or geology training, and two years of teacher education. Pre-Bologna teacher education models were not standardised and can vary, but are essentially equivalent in the nature of the learning fostered. Upon becoming qualified, novice teachers must enter a yearly national teacher contest to apply for teaching. Then, they usually spend their first practicing years teaching in different schools throughout the country before becoming allocated to a given school. Inservice Portuguese teachers are required to attend continuing training in order to obtain credits necessary for their career progression. While the number of credits is determined by the Ministry of Education, teachers are given the chance to decide the areas in which to receive the training. The Ministry of Education defines biology and geology as the major domains in which biology teachers must have training in order to teach 12th grade biology, but specific training in biotechnology education is only available as non-mandatory continuing education courses.

Considering the diverse academic profiles of Portuguese biology teachers and the considerable national mobility that characterises their professional path, sample representativeness can be achieved by random participant selection. A total of 150 teachers from 20 secondary schools (16 public and 4 private) were asked to enter the study, by sending formal invitations to their schools' executive boards and/or to the biology teachers' representatives. Taking into account all ethical requirements, the respondents were informed about the nature and aims of the study and their anonymity was assured. Aiming to increase the size of the sample, teachers were asked to enquire the availability of other colleagues to answer the questionnaire. However, only 97 questionnaires were returned, representing a 64.67% response rate in relation to the 150 teachers initially contacted. This rate may have been lower depending on the number of indirect invitations established. Although a response rate of approximately 50% is considered acceptable for most survey studies (Babbie, 2008), the respondents' profiles were analysed to assure that they were representative of the Portuguese biology teacher population. After exclusion of four participants who provided severely incomplete responses, the final study sample comprised 93 teachers.

The respondents' (78 females, 15 males) age ranged from 25 to 59 (M=40.03, SD= 9.01). The sample included teachers with diverse initial training backgrounds, in biology (n=42), biology and geology (n=42), and geology (n=8), and different qualifications, BSc (n=71), MSc (n=21), and one PhD (*Supporting information – Fig. IV.S1*). Their general teaching experience ranged from less than one to 36 years (M=16.02, SD=9.70). There were 59 teachers with experience in teaching 12th grade biology and 33 who had never taught the subject (one teacher did not answer the question). In spite of being inexperienced in teaching biotechnology contents, these 33 teachers' beliefs should be analysed, as they will likely be required to teach these contents within the next few years. Only 26 respondents reported to have attended complementary training in biology, such as short-term courses on subjects ranging from general laboratory procedures to health issues (*Supporting information – Fig. IV.S2*). Eleven of these teachers were engaged in workshops covering biotechnology-related topics and methods (*Supporting information – Table IV.S1*).

A characterisation of the study sample is provided as *supporting information in Table IV.S1.*

Measurement instrument

A multi-dimensional questionnaire (Appendix IV.A1) was designed by adapting items from instruments published in studies conducted in different countries (Bryce & Gray, 2004; Cabo Hernández et al., 2006; Chen & Raffan, 1999; Dawson, 2007; Gaskell et al., 2006; Klop & Severiens, 2007; Macer, Asada, Tsuzuki, Akiyama, & Macer, 1996; Miles, Ueland, Oslash, Øydis, & Frewer, 2005; Steele & Aubusson, 2004; Wilson, Kirby, & Flowers, 2002). The content validity of the instrument was assessed by the scrutiny of two biology teachers with more than 15 years of teaching experience and its construct validity was evaluated through psychometric analyses. Part I of the questionnaire included an introductory note informing about the aims of the study and assuring anonymity, and several socio-demographic questions. Part II consisted of 13 questions organised in three sections to assess: (i) teachers' beliefs about biotechnology; (ii) teachers' beliefs about biotechnology education and the main obstacles they must overcome to engage in it; (iii) information sources about biotechnology they use and trust. To enhance teachers' collaboration and prevent them from feeling evaluated, which could compromise the reliability of their answers (Oppenheim, 1992), the relationship between their knowledge and beliefs was evaluated indirectly, by integrating the data implicit in their responses throughout the different sections of the questionnaire.

Teachers' beliefs about biotechnology were assessed by appraising the importance they attribute to it, their attitudes towards it, and their interest in it (questions Q1-Q5, Appendix IV.A1), using five-point Likert-type scales. Considering that attitudes are complex multidimensional constructs determined by the interaction of cognitive, affective and behavioural factors, the attitudes items were organised according to the tripartite model of attitudes (Klop & Severiens, 2007; Rosenberg & Hovland, 1960). The cognitive component of teachers' attitudes (question Q2, Appendix IV.A1) was evaluated by measuring their approval of different applications and procedures. In the affective component sub-section (question Q3, Appendix IV.A1), teachers were asked to rate their agreement with issues such as human embryo research, or GM food labelling. To assess the behavioural component of teachers' attitudes (question Q4, Appendix IV.A1), their intentions to buy GM products or to allow access to their genetic information were investigated.

The second section of part II included four questions addressing teachers' beliefs about biotechnology teaching (Q10-Q13, Appendix IV.A1). In question Q10 teachers were asked to rate their agreement on a five-point scale with 17 statements about aspects that influence teaching. In question Q11 the frequency with which teachers adopt behaviours that contribute to improve their practice was measured using five-point Likert-type items. Finally, questions Q12 and Q13 enquired teachers' interest in implementing biotechnology-related practical activities in their classrooms and attending complementary training about biotechnology.

The selection teachers make of information conveyed by different sources and communication agents impacts their practice, by influencing the accuracy of their knowledge and the quality of the materials they provide to students (Duke & Ward, 2009), thus influencing the success of teaching-learning processes. Underpinned by this premise, questions Q6, Q7 and Q8 (Appendix IV.A1) were formulated to evaluate teachers' decisions to use information sources according to their availability and credibility. Question Q6 asked teachers to evaluate how well-informed they thought they were about the subject, question Q7 asked them to identify the sources they most frequently used from a list of 13 options, and in question Q8 they were asked to rate the trust they place in 14 communication sources in a five-point scale.

Data collection and analyses

The fieldwork was conducted from June 2009 to February 2010. A printed and an electronic version of the questionnaire were developed and administered in the respondents' native language in hand and by e-mail, respectively. The two versions were identical, in order to reduce differences in teachers' responses. For instance, the form fields in the electronic questionnaire were not limited in length and allowed the selection of more than one option, as can happen in printed surveys if the answering instructions are overlooked. The respondents could go back to previous questions and there was no time limit for the completion of either type of survey. Teachers returned the electronic questionnaires by e-mail, and the printed questionnaires were collected from schools by the researchers.

The data collected were codified, recorded, cleansed and subjected to descriptive and missing values analyses to assess its suitability for further examination. One item, Q10j (Appendix IV.A1), for which the non-response rate was 9.7%, was eliminated. Imputation of missing values for the remaining items was performed by linear interpolation (Twisk & de Vente, 2002). The dimensionality and the psychometric properties of the data gathered were assessed by subjecting the ordinal scales in the questionnaire to an EFA (PCA with varimax rotation), and by performing reliability analyses. EFA is an exploratory method that allows analysing data variations in search for latent factors that account for the variability of a larger set of measured variables (Henson & Roberts, 2006). This method can also be used to assess construct validity by providing an estimate of the degree in which the variables measure the intended constructs (Hayton, Allen, & Scarpello, 2004). It was decided to employ an exploratory approach, rather than a confirmatory, because the instrument used in this study was newly developed (Worthington & Whittaker, 2006). A minimum sample size of 100 effective respondents is considered reasonable for EFA (Wasserman & Bracken, 2003). While this places the size of the study sample at the limit of acceptability, it has been demonstrated that the adequate sample size for EFA depends on the nature of the data (Costello & Osborne, 2005; MacCallum, Widaman, Zhang, & Hong, 1999). To determine the adequacy of the sample for factor analysis, the factorability of the dataset was evaluated using the Kaiser-Meyer-Olkin (KMO) measure and the Bartlett's test of Sphericity (Worthington & Whittaker, 2006), and the quality of the factor structures identified was assessed considering elements such as communalities and loading scores (Costello & Osborne, 2005; MacCallum et al., 1999). The KMO score threshold for a satisfactory factor analysis to proceed was set at 0.50 (Sharma, 1996), and the significance of the correlation pattern among the variables through Bartlett's test was determined for a confidence interval of 95% (Ho, 2006). Factor retention was decided based on the Kaiser criterion (eigenvalues greater than 1), the scree test and the interpretability of the results (Hayton et al., 2004). Items were considered for analyses when they were not freestanding, cross-loading, decreasing the scale's internal consistency, and displayed communalities and loadings above 0.40 (Costello & Osborne, 2005).

Reliability analyses were performed using the Cronbach's alpha coefficient and the Kuder-Richardson formula 20 (KR-20) for ordinal and dichotomous variables, respectively. These indexes provide an average of all split-half coefficients that would result from every possible division of the scales in half and produce scores ranging from 0.00 to 1.00 (Gravetter

& Forzano, 2009). Measures were considered reliable for scores above 0.60 (Wasserman & Bracken, 2003).

Frequencies were calculated for each dichotomous item in question Q7 (Appendix IV.A1) and mean scores were determined for each ordinal item of the questionnaire, as well as for the factors identified through EFA. Global mean scores were calculated for each of the attitudes' components, for the attitudes sub-section as a whole, for question Q10 (Appendix IV.A1), and for question Q11 (Appendix IV.A1), after recoding reversed items so that higher scores corresponded to more positive assessments. Mean responses were examined by performing Student's *t*-tests. One-sample *t*-tests were used to compare the respondents' mean responses with the midpoint of the test variables. By setting a test value of 3 in a five-point scale, it was determined if the respondents' positioning was neutral, positive or negative. For a confidence interval of 95%, mean responses that were not significantly different from 3 were considered indicative of a neutral assessment, and mean responses that were significantly higher or lower than 3, were interpreted as positive or negative assessments, respectively. Cohen's *d* was used to measure the strength of the mean differences observed (Cohen, 1988). Size effects were considered small, medium or large when they were equal to 0.2, ranging from 0.5 to 0.8, or above 0.8, respectively (Cohen, 1988; Gravetter & Forzano, 2009). The correlations between the variables were assessed using Spearman's rank correlation coefficient and the strength of the relationships was interpreted based on the values described in De Vaus (2002): scores were considered low, moderate or large, when they were below 0.30, between 0.30 and 0.50, or above 0.50, respectively.

Hierarchical cluster analysis (Ward's method, squared Euclidean measure of distance) was carried out to screen the whole sample for homogenous sub-groups of teachers sharing identical beliefs, using all the ordinal items as variables. Ward's method was used as a clustering method to optimise the minimum variance within the clusters identified (Hill & Lewick, 2006).

To evaluate the influence of teachers' general features on their beliefs, the respondents' age, teaching experience (globally and in 12th grade biology), qualifications, initial training background, and complementary training in biology and biotechnology were crossed with cluster membership. Considering the possibility that the cluster analysis may have masked differences in teachers' responses, the respondents' profiles were also crossed with the scores of each individual item in the questionnaire, and with each of the composite variables computed following psychometric analyses. Spearman's rank correlation coefficient was used for ordinal variables. For nominal variables, Chi-square tests were performed and Pearson's Ø and Cramér's *V* were used as measures of association (David & Sutton, 2004).

Data analyses were conducted using SPSS v.17.0.

Results and Discussion

Teachers' beliefs about biotechnology

Teachers are major contributors for the promotion of future generations' scientific literacy. Considering that their orientation to specific subjects is known to affect their practice (Van Driel et al., 2007) and can assist in predicting their instructional decisions (Gess-Newsome, 1999; Nespor, 1985; Wallace & Kang, 2004), it is essential to understand their beliefs about biotechnology.

Teachers believe that biotechnology is important and interesting

Previous research has revealed that, regardless of how positively or negatively the public assesses the implications of biotechnology, there is general agreement on the importance of biotechnology applications for the improvement of the quality of life (Gaskell et al., 2006; Pardo, Midden, & Miller, 2002). The data gathered in this study are consistent with these observations and demonstrate that Portuguese teachers hold similar beliefs about biotechnology to those of the general public. In fact, the teachers surveyed considered that biotechnology is an interesting (M=4.45, SD=0.63, $t(92)$=22.07, p=0.00, d=2.29) and important (M=4.41, SD=0.56, $t(92)$=24.37, p=0.00, d=2.52) subject, and these two dimensions were found to be positively correlated (Table IV.1). Teachers' attitudes were overall positive (M=3.37, SD=0.54, $t(92)$=6.69, p=0.00, d=0.69), although not associated with the importance attributed to biotechnology or the interest it elicits (p>0.05). Moreover, a closer look into main features of teachers' cognitive and affective responses indicates that they are optimistic about most of the applications considered in this study.

Table IV.1
Spearman's rank correlations between teachers' beliefs about biotechnology, biotechnology education, and their engagement in behaviours to improve their practice.

	Q1	**Q2, Q3 and Q4**	**Q5**	**Q6**	**Q9**	**Q10**	**Q11d and Q11e**	**Q11a, Q11b and Q11f**
Importance of biotechnology (Q1)	1.00	0.11	0.37**	-0.04	0.40**	0.02	0.24*	0.11
Attitudes towards biotechnology (Q2, Q3 and Q4)	0.11	1.00	0.04	0.27**	0.11	0.22*	0.03	-0.04
Interest in biotechnology (Q5)	0.37**	0.04	1.00	0.15	0.42**	0.16	0.09	0.16
Degree of information about biotechnology (Q6)	-0.04	0.27**	0.15	1.00	0.09	0.16	0.13	0.36**
Importance of biotechnology education (Q9)	0.40**	0.11	0.42**	0.09	1.00	-0.03	0.18	0.13
Perceived limitations to biotechnology teaching (Q10)	0.02	0.22*	0.16	0.16	-0.03	1.00	0.01	0.05
Participation in certified training programs and events (Q11d and Q11e)	0.24*	0.03	0.09	0.13	0.18	0.01	1.00	0.32**
Engagement in informal activities and collaborations (Q11a, Q11b, and Q11f)	0.11	-0.04	0.16	0.36**	0.13	0.05	0.32**	1.00

* indicates significant differences for α=0.05; ** indicates significant differences for α=0.01. Global scores were computed for *attitudes towards biotechnology* and *perceived limitations to biotechnology teaching* considering the items retained after psychometric analysis for questions Q2, Q3 and Q4, and Q10, respectively.

Teachers approve most biotechnology applications depending on their purpose

EFA results for the *cognitive component* scale reveal four factors accounting for 72.33% of the variance in the respondents' answers: *GMOs*, *classical applications*, *gene therapy,* and *human cloning*. This factor solution was obtained following the exclusion of two items from the original set: Q2l and Q2k (Appendix IV.A1), that in a previous analysis were cross-loading on three of the four factors identified, and that did not strengthen the scale's reliability. Internal consistency analysis' results support this factor structure with the exception of the factor *human cloning* (Table IV.2). Therefore, whereas mean scores were computed for the first three factors, the two items contributing for the factor *human cloning* were assessed individually. Teachers were optimistic about classical applications and gene therapy, and were indecisive about GMOs (Table IV.2). On the other hand, human cloning was among the least accepted types of applications. In fact, reproductive human cloning was highly disapproved by most of the respondents. Interestingly, contrasting with this clearly negative appraisal, therapeutic human cloning elicited a less resolute assessment (Table IV.2). These findings are consistent with a previously described tendency for therapeutic cloning to be viewed more favourably than reproductive cloning (Cabo Hernández et al., 2006; Nisbet, 2004). Most of the teachers answered positively to the manipulation of human genes for the treatment of genetic disorders, even in embryos (Table IV.2). While this could seem unexpected given the controversy surrounding human embryo research, it can derive from the acknowledgment that this research may be required in spite of the moral and ethical questions raised, as argued in previous studies (Nisbet, 2004). Conversely, teachers were uncertain about the production and use of GMOs (Table IV.2). The analysis of the structure of the factor *GMOs* reveals that the six items loading on this factor (Table IV.2), mention different types of GMOs with diverse applicability. Previous research has demonstrated that the purpose of the application and the type of organism manipulated are two major elements that affect teachers support for GMOs (Šorgo & Ambrožič-Dolinšek, 2010). Not only does this study confirm those findings, but also, according to the individual scores for the items mentioning GMOs, it further indicates that the purpose of the application may have a greater impact than the organism manipulated on teacher acceptance of GMOs.

Table IV.2

Teachers' approval of biotechnology applications.

Factor structure of the *cognitive component of attitudes* scale based on exploratory factor analysis and reliability analysis.

Item	h^2	Identifiable Factors				*M (SD)*	*t(92)*	*p*	*d*
		GMOs	*Classical applications*	*Gene therapy*	*Human cloning*				
Q2h *Use of GM cows in the production of medicines for human*	0.66	0.80				3.10 (1.19)	0.79	0.44	0.08
Q2i *Production of pesticide resistant plants by gene manipulation*	0.74	0.78			0.36	2.91 (1.20)	-0.69	0.49	0.07
Q2d *Plant growth improvement in saline environments by gene alteration*	0.73	0.77				3.40 (1.07)	3.64	0.00	0.38
Q2j *Genetic modification of tomatoes to make them ripen more slowly and have a longer shelf life*	0.59	0.73				2.74 (1.22)	-2.05	0.04	0.21
Q2c *Use of GM microorganisms in waste treatment*	0.61	0.72		0.32		3.88 (1.10)	7.72	0.00	0.80
Q2g *Insertion of plant genes into animals*	0.68	0.70			0.35	2.74 (1.03)	-2.46	0.02	0.26
Q2a *Use of yeast in the production of bread, wine and beer*	0.87		0.92			4.79 (0.62)	27.63	0.00	2.87
Q2b *Use of yeast in animal food production*	0.86		0.91			4.54 (0.81)	18.29	0.00	1.89
Q2f *Treatment of genetic disorders by human gene manipulation*	0.80			0.89		4.01 (0.92)	10.62	0.00	1.10
Q2e *Treatment of genetic disorders by embryonic gene manipulation*	0.76			0.80		3.53 (1.17)	4.37	0.00	0.45
Q2m *Use of human cloning for therapeutic purposes*	0.72				0.81	3.11 (1.44)	0.72	0.47	0.08
Q2n *Use of human cloning with reproductive purposes*	0.67				0.80	1.87 (1.23)	-8.88	0.00	0.90
Eigenvalue		4.59	1.69	1.33	1.07				
% of variance		38.26	14.05	11.08	8.94				
Cronbach's alpha		0.86	0.83	0.71	0.58				
M		3.13	4.66	3.77					
(*SD*)		(0.89)	(0.67)	(0.93)					
t(92)		1.40	23.94	8.02					
p		0.17	0.00	0.00					
d		0.15	2.48	0.83					

Coefficients below 0.30 were suppressed. KMO=0.79. Bartlett's Test of Sphericity: $\chi^2(66)=463.57$, $p=0.00$. h^2 - communality coefficient. *M* - Mean. *SD* - Standard Deviation. One-sample *t*-test performed for test value=3. *d* - Cohen's *d* measure of effect size.

Regarding the *affective component* scale, the disperse (KMO=0.48) and not statistically significant ($\chi^2(6)=8.20$, $p=0.22$) pattern of correlations between the variables measured, denoted that the scale developed was unfit for factor analysis. Whether or not a set of items conforms to a factor structure, their individual examination can offer additional information to identify and interpret specific relationships between variables, as long as their predictive power is not overinterpreted (Maruish, 1999). Accordingly, items Q3a, Q3b, Q3c, and Q3d (Appendix IV.A1) were retained and analysed individually because of the valuable information they provide. For instance, teachers' were not sure if human embryo research should be authorised (M=3.03, SD=1.18, $t(92)$=0.27, p=0.79, d=0.03). However, their cognitive assessment of human embryo research, as previously demonstrated by the average approval of genetic disorder treatment through gene manipulation (Table IV.2), suggests that they are aware and value its beneficial biomedical consequences. Consistently with what has been described for adult populations across various countries (Einsiedel, Premji, Geransar, Orton, Thavaratnam, & Bennett, 2009; Gaskell et al., 2006), the respondents' answers reflect a conflict between a deontological and utilitarian assessment of human embryo research, with a tendency to privilege the latter by acknowledging the health benefits implied. In fact, the respondents were favourable about biomedical applications and most of them agreed that future generations will benefit from advances in this field (M=4.40, SD=0.74, $t(92)$=18.40, p=0.00, d=1.89).

Teachers' approval of biotechnology applications is determined not only by their purpose, but also by their usefulness

Teachers' behavioural intentions towards biotechnology emphasise the impact of the application's purpose on its perceived acceptability. The KMO score for the *behavioural component* scale confirms the sample's adequacy for factor analysis, and the Barlett's test indicates a statistically significant correlation between the variables (Table IV.3). A two-factor solution accounting for 69.75% of the variance registered was identified for this scale: *purchasing intention* and *allowing access to one's genetic information* (Table IV.3). However, the internal consistency score for the factor *allowing access to one's genetic information* was below the threshold of acceptability (α<0.60) and consequently the two items it included were analysed individually. It was observed that teachers were willing to do genetic tests for disease diagnosis, but were reluctant to provide genetic information for inclusion in databases (Table IV.3). These findings also indicate that teachers support their beliefs on the usefulness of the applications, as acknowledged in previous studies (Gaskell et al., 2006; Šorgo & Ambrožič-

Dolinšek, 2010). Consistently with their uncertainty about the acceptability of GMOs, teachers were also indecisive about purchasing GM products (Table IV.3).

Table IV.3
Teachers' behavioural intentions towards biotechnology applications.
Factor structure of the *behavioural component of attitudes* scale based on exploratory factor analysis and reliability analysis.

		Identifiable Factors					
Item	h^2	***Purchasing intention***	***Allowing access to one's genetic information***	***M (SD)***	***t(92)***	***p***	***d***
Q4a *How often would you buy transgenic foods if they were easily available in supermarkets?*	0.83	0.91		2.41 (0.93)	-6.05	0.00	0.63
Q4b *How often would you buy medicines obtained by genetic manipulation?*	0.64	0.80		3.04 (1.16)	0.31	0.75	0.03
Q4e *How often would you buy transgenic foods if they were healthier than other foods?*	0.66	0.77		3.48 (1.16)	3.98	0.00	0.41
Q4d *How often would you give the police access to your genetic information?*	0.70		0.84	2.72 (1.42)	-1.90	0.06	0.20
Q4c *How often would you do a genetic test for medical diagnostic?*	0.65		0.79	4.31 (0.91)	13.92	0.00	1.44
Eigenvalue		2.27	1.22				
% of variance		45. 32	24.43				
Cronbach's alpha		0.77	0.50				
M		2.98					
(*SD*)		(0.90)					
t(92)		-0.25					
p		0.80					
d		0.03					

Coefficients below 0.30 were suppressed. KMO=0.56. Bartlett's Test of Sphericity: $\chi^2(10)=118.60$, $p=0.00$. h^2 - communality coefficient. *M* - Mean. *SD* - Standard Deviation. One-sample *t*-test performed for test value=3. *d* - Cohen's *d* measure of effect size.

The cross-examination of teachers' cognitive, affective and behavioural attitudinal responses suggests that there is a greater impact of the cognitive element (r_s=0.41, n=93, p=0.00) than of the affective (r_s=0.31, n=93, p=0.00) on their behavioral intentions. Because the correlation coefficients indicate moderate relationships, these outcomes must be interpreted as tendencies. Nevertheless, drawing on the notion that the attitudes' cognitive component encompasses conceptual reasoning and understanding about the object evaluated

(Aiken, 2002), our findings suggest that the contribution of knowledge for the development of teachers' beliefs about biotechnology cannot be dismissed. Furthermore, the data indicate that the respondents' ability to mildly detach from a purely affective engagement with biotechnology's repercussions enables them to undertake an objective appreciation of the advantages of its applications. This evidences that teachers can address biotechnology from a less emotional perspective. Considering that teachers' instructional decisions have been known to be more linked to their beliefs than driven by exclusively rational criteria (Nespor, 1985; Wallace & Kang, 2004), it is important to understand how these teachers' beliefs about biotechnology relate to their beliefs about biotechnology education.

Teachers' selection of information sources about biotechnology

Until now, the few studies that have focused on how science teachers select information have shown that they use a limited number of readily available sources, mainly due to time limitations and the perception that they lack the skills to properly evaluate them (Sun & Liu, 2009; Williams & Coles, 2007; Wilson et al., 2002). In this study, although teachers found themselves to be reasonably informed about biotechnology (M=3.30, SD=0.59, $t(92)$=4.96, p=0.00, d=0.51), the data about the sources of information they use and trust support these observations. Furthermore, these data also sustain that the reliability of those sources is a factor that influences teachers' choices, reinforcing what is described for other populations (Brossard & Nisbet, 2007; Costa-Font, Gil, & Traill, 2008).

Teachers restrict their search for information to a limited number of sources

The internal consistency score for the set of items mentioning information sources about biotechnology (Q8, Appendix IV.A1) was below the threshold of acceptability (KR20=0.50). However, considering that this question makes available information that cannot be efficiently measured as an unique dimension (Guion & Highhouse, 2006), all items were upheld for analysis. From the 13 options listed, the respondents selected the internet (86%), scientific magazines (79%) and school textbooks (71%) as the three most frequently used sources of information (*Supporting information – Fig. IV.S3*). More than half of them also selected the television (60%) and scientific papers (57%). The least commonly used sources were workshops (13%), the radio (11%), and exhibitions (9%). The main aspect that emerges from this selection is that teachers tend to retrieve information from the most readily available sources, as previously described (Williams & Coles, 2007). This suggests that the need for teachers to be up-to-date with such as fast-growing and often controversial field as biotechnology does not compel them to actively search information in more specialised sources, even though the lack of time to conduct more thorough searches cannot be ruled out. This outcome may also reflect the scarcity of training programs purposely developed for Portuguese teachers. Although, for instance, the European Molecular Biology Laboratory (http://www.embl.de/) has been promoting workshops on molecular biology and biotechnology topics and techniques for European teachers.

Availability may be more determining than reliability in teachers' selection of information about biotechnology

EFA results for the scale measuring the trust teachers place in 14 information sources reveal a four-factor solution explaining 65.60% of the variance observed, and supported by the reliability analysis (Table IV.4). According to this solution, the trust teachers placed in the various entities and agents presented allows them to be grouped in: *industrial and commercial entities*, *non-governmental organisations (NGOs) and informal sources*, *scientific research and educational agents*, and *governmental entities and legislators* (Table IV.4). The average factor scores indicate that scientific research and educational agents are considered the most reliable sources of information, followed by NGOs and informal sources. According to the findings in the 2005 EB survey (Gaskell et al., 2006), most Europeans opt for a *principle of scientific delegation*, transferring to experts the decisions about biotechnology. While the high levels of trust placed in *scientific research and educational agents* (Table IV.4) cannot be unequivocally linked to the endorsement of this principle, they denote a predisposition for a deference to scientific authority, as pointed out by Brossard & Nisbet (2007). Moreover, this predisposition becomes particularly pronounced when they evaluate other stakeholder groups, such as industrial and legislative entities (Table IV.4). Teachers' assessment of these sources meets previous studies reporting that consumer trust is higher for environmental organisations than for industrial and, particularly, governmental agencies (Costa-Font et al., 2008; Gaskell et al., 2006). Most importantly, these results further add that teachers are critical in their appraisal of the reliability of the information about biotechnology provided by different agents.

Table IV.4
Teachers' trust in information sources about biotechnology.
Factor structure of the *trust in information sources* scale based on exploratory factor analysis and reliability analysis.

ITEM	h^2	IDENTIFIABLE FACTORS				*M* *(SD)*	*t(92)*	*p*	*d*
		Industrial and commercial entities	***NGOs and informal sources***	***Scientific research and educational agents***	***Governmental entities and legislators***				
Q8d *Agro-food industry*	0.82	0.88				2.74 (0.79)	-3.14	0.00	0.33
Q8e. *Health industry*	0.79	0.86				3.13 (0.89)	1.40	0.16	0.15
Q8c *Pharmaceutical industry*	0.79	0.84				3.19 (0.95)	1.97	0.05	0.21
Q8k *Consumer rights organisations*	0.72		0.77		0.35	3.76 (0.77)	9.54	0.00	0.99
Q8j *Environmental organisations*	0.72	0.32	0.75			3.30 (0.75)	3.83	0.00	0.40
Q8i *Internet*	0.56		0.60	0.40		2.95 (0.71)	-0.73	0.47	0.08
Q8m *Medical doctors*	0.67		0.59	0.35	0.45	3.76 (0.81)	9.06	0.00	0.94
Q8a *Media*	0.28		0.46			2.93 (1.14)	-0.63	0.53	0.07
Q8h *Scientists*	0.76			0.84		4.39 (0.68)	19.78	0.00	2.05
Q8b *Scientific magazines*	0.61			0.76		4.54 (0.58)	25.50	0.00	2.64
Q8g *Universities*	0.67			0.70	0.31	4.37 (0.62)	21.18	0.00	2.20
Q8n *Politicians*	0.55				0.73	1.90 (0.93)	-11.33	0.00	1.18
Q8l *European Union*	0.63				0.69	3.50 (0.89)	5.35	0.00	0.56
Q8f *Governmental agencies*	0.62	0.48			0.61	2.98 (0.78)	-0.27	0.79	0.03
Eigenvalue		4.50	1.88	1.56	1.24				
% of variance		32.17	13.43	11.17	8.83				
Cronbach's alpha		0.89	0.67	0.74	0.67				
M		3.02	3.34	4.43	2.79				
(*SD*)		(0.79)	(0.56)	(0.51)	(0.68)				
t(92)		0.26	5.84	27.18	-2.97				
p		0.79	0.00	0.00	0.00				
d		0.03	0.61	2.82	0.31				

Coefficients below 0.30 were suppressed. KMO=0.77. Bartlett's Test of Sphericity: $\chi^2(91)=491.76$, $p=0.00$. h^2 - communality coefficient. *M* - Mean. *SD* - Standard Deviation. One-sample *t*-test performed for test value=3. *d* - Cohen's *d* measure of effect size. NGOs -Non-governmental organisations.

The comparison between the sources most frequently used by the teachers and the trust they place in them demonstrates that their choices are influenced both by reliability and availability. For instance, in spite of admitting to frequently use the internet, the television, and magazines, teachers had reservations about the trust to place in these informal sources (Table IV.4). This suggests that they attempt to base their decisions in source credibility, a more rational and less arbitrary criterion than readily availability, but that they often conform to the latter, raising the question of which are the reasons underlying this behaviour. In a study on the use teachers make of research evidence, Williams and Coles (2007) reported that more than half of the 390 participants used the most readily available information due to time limitations or because they could not access specialised information directly from the school. Taking these findings into account, it can be argued that in the present study the participants' management of information sources about biotechnology was influenced by the time required to access them. However, teachers' responses can also reflect difficulties in identifying and selecting accurate and reliable information, which can be troublesome given the rapid advancements in biotechnology and the controversy surrounding it. In fact, one cannot dismiss that teachers' choices about information use are affected by their information literacy. For instance, limited information literacy skills have been associated with an exacerbated perception of challenges posed at the use of specific information sources (Williams & Coles, 2007).

Teachers' beliefs about biotechnology education

Several authors emphasise the need to acknowledge teachers' beliefs when planning to change or improve their practice (Bryan & Atwater, 2002; Van Driel et al., 2007; Wallace & Kang, 2004). Teaching outcomes are known to be strongly influenced by the beliefs teachers hold about teaching, learning, curriculum objectives and subject matter to be taught (Gess-Newsome, 1999).

Therefore, it is necessary to understand teacher's beliefs about biotechnology education and to identify factors that influence them. In this study, most of the teachers considered biotechnology education to be very important (M=4.63, SD=0.70, $t(92)$=22.40, p=0.00, d=2.32), although they believed that there are relevant limitations to biotechnology teaching. These limitations were identified by asking teachers to rate their agreement with statements about elements that affect their practice (question Q10, Appendix IV.A1). EFA results for the scale developed revealed a four-factor solution explaining 76.58% of the variance observed: *school textbooks and other educational resources*, *materials and infrastructures in schools*, *activity planning and implementation*, and *12th grade biology curriculum and schedule* (Table IV.5). The KMO score and the results of Bartlett's test demonstrate the sample's adequacy, and the factor structure is supported by the internal consistency outcomes (Table IV.5). Although this solution excludes items Q10a, Q10b, Q10e, Q10h, Q10l, and Q10p (Appendix IV.A1), they were analysed and interpreted individually to avoid a meaningful loss of information, as recommended in Maruish (1999). A global mean score for question Q10 was computed considering the four factors and the six individual items. Consistently with prior reports (Steele & Aubusson, 2004), this score reveals that the participants find their practice to be compromised by different aspects (M=2.81, SD=0.32, t(92)=-3.11, p=0.00, d=0.32), mainly concerning the lack of materials and infrastructures, the poor quality of school textbooks and limited availability of other educational resources, and time management constraints related with activity planning and development (Table IV.5). Conversely, the participants considered that the 12th grade biology curriculum covers biotechnology adequately and that the length of biology classes at this level allows the development of activities about biotechnology (Table IV.5).

Concerning teachers' engagement in behaviours to improve their practice, the scale developed is compatible with a two-factor structure, accounting for 63.64% of the variance observed in their answers, and grouping their behaviours into: engagement in *informal activities* and *collaborations*; and participation in *certified training* programs and events. The KMO score for the scale is acceptable, the correlations between the variables are significant, and the factor solution identified is supported by the reliability analysis (Table IV.6). Both globally (M=2.81, SD=0.31, t(92)=-6.11, p=0.00, d=0.61), and according to both factors identified, teachers tend to seldom participate in training programs and other events, seek for expert collaboration, and explore informal learning environments (Table IV.6).

Table IV.5

Teachers' beliefs about the limitations posed at biotechnology teaching.

Factor structure of the *limitation to biotechnology teaching* scale based on exploratory factor analysis and reliability analysis.

ITEM	h^2	IDENTIFIABLE FACTORS: *School textbook and other educational resources*	*Materials and infrastructures in schools*	*Activity planning and implementation*	*12^{th} grade biology curriculum and schedule*	*M (SD)*	*t(92)*	*p*	*d*
Q10f *School textbooks coverage of biotechnology is sufficient*	0.69	0.80				2.50 (0.73)	-6.66	0.00	0.69
Q10g *The information about biotechnology available in school textbooks is scientifically supported*	0.68	0.,77				2.98 (0.85)	-0.25	0.81	0.03
Q10k *There are enough educational resources about biotechnology available for teachers*	0.62	0.73				2.20 (0.82)	-9.42	0.00	0.98
Q10o *There are enough educational resources about biotechnology available for students*	0.73	0.70	0.48			2.39 (0.74)	-8.01	0.00	0.83
Q10n *Schools have adequate resources for the development of activities about biotechnology*	0.91		0.95			1.96 (0.81)	-12.47	0.00	1.29
Q10m *Schools have adequate settings for the development of activities about biotechnology*	0.87		0.91			2.14 (0.90)	-9.18	0.00	0.95
Q10c *Planning classes addressing biotechnology contents requires more work than preparing other classes* **(R)**	0.86			0.92		3.31 (1.10)	2.73	0.01	0.28
Q10d *Developing activities about biotechnology is more time consuming than developing other type of activities* **(R)**	0.84			0.89		3.17 (1.00)	1.67	0.10	0.17
Q10q *The duration of 12^{th} grade biology classes allows the development of activities about biotechnology*	0.71				0.86	3.38 (1.07)	3.41	0.00	0,35
Q10i *Biotechnology is adequately addressed in the 12^{th} grade biology program*	0.74				0.81	3.67 (0.87)	7.36	0.00	0.77
	Eigenvalue	2.56	2.06	1.83	1.21				
	% of variance	25.58	20.59	18.34	12.07				
	Cronbach's alpha	0.74	0.90	0.81	0.64				
	M	2.52	2.05	2.76	3.52				
	(*SD*)	(0.59)	(0.82)	(0.96)	(0.84)				
	t(92)	-7.92	-11.22	-2.42	6.02				
	p	0.00	0.00	0.02	0.00				
	d	0.82	1.16	0.25	0.63				

Coefficients below 0.30 were suppressed. KMO=0.61. Bartlett's Test of Sphericity: $\chi^2(45)=340.05$, $p=0.00$. h^2 - communality coefficient. *M* - Mean. *SD* - Standard Deviation. The two negative items identified with **R** were reversed to calculate the overall score for the scale. One-sample *t*-test performed for test value=3. *d* - Cohen's *d* measure of effect size.

Table IV.6

Teachers' engagement in behaviours that contribute to improve their practice in biotechnology education.

Factor structure of the *engagement in behaviours to improve teachers' practice* scale based on exploratory factor analysis and reliability analysis.

ITEM	h^2	IDENTIFIABLE FACTORS: *Informal activities and collaborations*	IDENTIFIABLE FACTORS: *Certified training*	*M (SD)*	*t(92)*	*p*	*d*
Q11a *How often do you use information sources about biotechnology to keep up-to-date?*	0.61	0.78		3.89 (0.98)	8.75	0.00	0.91
Q11f *How often do you organise visits to non-formal education contexts (for instance science centres or open days at universities) to promote biotechnology education?*	0.56	0.74		2.93 (1.23)	-0.51	0.62	0.05
Q11b *How often do you ask universities for collaboration in preparing classes about biotechnology?*	0.57	0.69	0.31	2.09 (1.00)	-8.78	0.00	0.91
Q11c *How often do you contact experts in the field of biotechnology to give lectures in the school?*	0.61	0.65	0.44	2.23 (1.12)	-6.64	0.00	0.69
Q11e *How often do you participate in training courses about biotechnology?*	0.81		0.90	2.41 (1.11)	-5.16	0.00	0.53
Q11d *How often do you attend conferences about biotechnology?*	0.67	0.33	0.75	2.88 (1.04)	-1.10	0.28	0.11
	Eigenvalue	2.61	1.21				
	% of variance	43.42	20.22				
	Cronbach's alpha	0.72	0.64				
	M	2.79	2.65				
	(*SD*)	(0.81)	(0.92)				
	t(92)	-2.58	-3.72				
	p	0.01	0.00				
	d	0.27	0.39				

Coefficients below 0.30 were suppressed. KMO=0.73. Bartlett's Test of Sphericity: $\chi^2(15)=120.10$, $p=0.00$. h^2 - communality coefficient. *M* - Mean. *SD* - Standard Deviation. One-sample *t*-test performed for test value=3. *d* - Cohen's *d* measure of effect size.

Teachers feel competent to teach biotechnology

Teachers made a positive assessment about their ability to teach biotechnology, by indicating the adequacy of their academic background (*M*=3.28, *SD*=0.96, *t*(92)=2.81, *p*=0.01, *d*=0.29). Interestingly, although the discussion of biotechnology's ethical and social implications is usually thought to be a key challenge for teachers (Bryce & Gray, 2004), there was a noticeable agreement with the need to discuss these aspects with the students (*M*=4.50, *SD*=0.65, *t*(92)=22.07, *p*=0.00, *d*=2.29). However, this does not imply that the respondents really address ethical issues in the classroom, as this may be compromised by other factors, namely the content and organisation of the curriculum or the time required to prepare and teach the classes (Bryce & Gray, 2004).

It has been shown that update courses and continuing training impact positively on how teachers' perceive their capacity to teach biotechnology, even when they already feel competent to do it (Bryce & Gray, 2004; Steele & Aubusson, 2004). However, even though most of the participants were indeed confident on their abilities in this regard, only 13% had participated in workshops, and less than half had attended conferences as well. Although the limited conference and workshop attendance scores (Table IV.6) could be due to teachers' lack of interest, this does not seem to be the case, as 97% of the respondents reported to be interested in participating in workshops about biotechnology. Another explanation may rely on the limited availability of complementary training purposely intended for Portuguese teachers. This assumption seems particularly reasonable considering that most of the respondents believed that the offer of inservice training courses is scarce (*M*=2.11, *SD*=0.85, *t*(92)=-10.09, *p*=0.00, *d*=1.05), regardless of how well informed about biotechnology they considered themselves to be (r_s=0.00, *n*=93, *p*=0.97). These data together with what was discussed in section 5.2.1., suggest that the lack or limited availability of continuing training can be an important limitation for teachers' practice.

Teachers believe that biotechnology is adequately addressed in the 12th grade biology curriculum

Contrasting with a previously acknowledged tendency for science teachers to avoid teaching biotechnology due to the perception that it is difficult for the students (Steele & Aubusson, 2004), the teachers surveyed considered that students do not find biotechnology a particularly difficult topic (M=3.09, SD=0.80, $t(92)$=1.03, p=0.30, d=0.11). Furthermore, they reported that students are interested in it (M=4.01, SD=0.72, $t(92)$=13.64, p=0.00, d=1.41). The fact that students' understanding of biotechnology was not the major limitation identified by these teachers is not surprising given the diversity of biotechnology-related issues that can be addressed in the classroom. To some extent, the perceived intelligibility of biotechnology is related with the curricular topics teachers must enact with. The nature, structure and extensiveness of science curricula can jeopardise teachers' decision to teach biotechnology (Kidman, 2009; Steele & Aubusson, 2004; Usak et al., 2009). Nevertheless, in this study the respondents considered appropriate the biotechnology coverage in the secondary science curriculum (Table IV.5), which as described in section 4, emphasises genetics and molecular biology contents (DGIDC, 2004). Because it is known that teachers' beliefs about student learning and about curricular goals shape their conduct (Gess-Newsome, 1999), the respondents' positive beliefs in that regard suggest that these elements do not impact negatively on their actions.

Teachers believe that planning biotechnology-related activities is work- and time- consuming

Schedule limitations in biotechnology education are another constraint commonly identified by teachers (Steele & Aubusson, 2004; Wilson et al., 2002). Studies have ascribed this response to the perception that the duration of science classes limits the range of activities that can be developed (Bryce & Gray, 2004; Hofstein & Lunetta, 2003). Contrasting with this assumption, in this study, teachers did not regard the lack of time to implement biotechnology-related activities as a major impairment. Currently, in Portuguese schools, 12th grade biology has a weekly schedule of 315 minutes organised in two class periods of 90 minutes and one of 135 minutes (www.dgidc.min-edu.pt), which the teachers considered to be adequate to the implementation of such activities (Table IV.5). Nevertheless, they shared the opinion that planning and developing activities in this scope is work- and time-consuming (Table IV.5). Actually, looking into detail to the items loading in the factor *activities development and implementation*, planning biotechnology-related activities was thought to be a greater obstacle than developing these activities (Table IV.5). Consistently with what was reported by Steele and Aubusson (2004), this may reflect teachers' unfamiliarity with the type of activities that can be developed, or their inexperience in preparing and developing them. For instance, teachers may be unaware of the existing "ready-to-use" classroom kits, complete with lesson plans, commercialised by companies like Bio-Rad Laboratories (www.bio-rad.com) or Fisher Scientific (http://www.fishersci.com/) that they can explore in their classes. This limited awareness of available educational resources can be related with the fact that teachers restrict their search for information to a limited number of sources.

Teachers believe that they lack infrastructures and educational resources to teach biotechnology

The respondents identified the insufficiency and/or inadequacy of materials and settings in schools as the most relevant limitations to biotechnology teaching (Table IV.5). Teachers have been reported to believe that the access to modern laboratory equipment would improve their teaching outcomes (France, 2007). And indeed, the unavailability of specialised settings and equipment can compromise teachers' practice. Nevertheless, nowadays there are countless resources specifically designed to address biotechnology concepts and techniques in classroom contexts, including web-based activities, laboratory kits, and experimental protocols (Keil & Palmer, 2009; Milne & Morrison, 2007; Rothhaar, Pittendrigh, & Orvis, 2006). In spite of their abundance, teachers reported the lack of educational resources for them and their students as the second most important limitation in biotechnology teaching (Table IV.5). As emphasised above, these results sustain that teachers may be unaware of how to search and/or adapt instructional materials, arguably because they use a limited number of easily available information sources. A clear example of this is illustrated by the individual scores for items Q10f and Q10g (Table IV.5). Although school textbooks were the third most frequently selected information source, teachers were uncertain about the scientific accuracy of their contents and thought that their coverage of biotechnology is insufficient (Table IV.5). In addition, teachers admitted to scarcely seek for the collaboration of universities and researchers to prepare and complement their classes (Table IV.6), in spite of placing scientists and universities among the most reliable providers of information about biotechnology.

Association between teachers' beliefs about biotechnology and their beliefs about biotechnology education

More than characterise teachers' beliefs about biotechnology and biotechnology education it is important to understand how they interact. As previously mentioned, biotechnology education was considered to be important by most of the respondents. And teachers' opinion was not related with their attitudes about biotechnology itself, but with the importance they attribute to it, and with the perception that it is an interesting issue for themselves (Table IV.1) and for their students (r_s=0.31, n=93, p=0.00).

Teachers' beliefs about the limitations posed at biotechnology education were not significantly correlated with the importance they give to biotechnology, to the teaching of its contents, or to the interest they have in it (Table IV.1). Nevertheless, there was a tendency for teachers with more positive attitudes towards biotechnology applications to be less negativistic about the obstacles posed at biotechnology teaching (Table IV.1). This might be interpreted as confirmation that teachers who are more optimistic about biotechnology are more prone to teach their students about it. However, this outcome must not be overestimated because, not only are these variables weakly correlated, but most importantly, teachers' attitudes were not associated with behaviours that contribute to assist and improve their practice (Table IV.1). In fact, the frequency with which teachers engage in these behaviours was not significantly correlated with their beliefs about the difficulties presented at biotechnology teaching, or about biotechnology itself (p>0.05), except for two situations (Table IV.1). There was a low positive correlation between the participation in courses and conferences and the importance teachers give to biotechnology, and, consistently with what has been argued about teachers' information retrieval and mobilisation competencies, the teachers' who reported to be more informed about biotechnology mentioned the use of informal contexts and the search for expert collaborations more frequently (Table IV.1).

These findings suggest that teachers' tendency to overestimate exogenous elements that impinge on their practice occurs regardless of how positive their beliefs about biotechnology and biotechnology education are. Considering the framework defined for this study, this indicates that teachers' practice is not only influenced by teachers' beliefs about biotechnology and biotechnology education, and by exogenous factors, but also by the beliefs they hold about these extrinsic elements as well. The shortcomings identified by the respondents are mainly related with the insufficiency and inadequacy of materials and resources, which can be mitigated by exploring alternative educational resources. An approach to overcome this problem includes the improvement of teachers' beliefs about practical limitations in biotechnology teaching. This can be achieved by developing training programs to promote teachers' information literacy in order to enhance their information research skills and enable them to better balance the practical constraints they face (Williams & Coles, 2007). Ultimately, this can contribute to promote their effective engagement in biotechnology education.

Identification of sub-groups of teachers with identical beliefs

The cluster analysis performed led to the identification of two subgroups of teachers with distinct belief patterns. These outcomes revealed that interest and importance, understood as endogenous and exogenous motivational elements respectively, as described by Ryan and Deci (2000), can have a differential contribution for teachers' beliefs. In cluster 1 (n=75), the perceived importance of biotechnology education was more strongly associated with the importance given to biotechnology (r_s=0.40, n=93, p=0.00) than with teachers' interest in it (r_s=0.29, n=93, p=0.00). Furthermore, within this cluster, the importance attributed to biotechnology was associated, although weakly, with teachers' attitudes towards biotechnology (r_s=0.23, n=93, p=0.04), which were globally positive (M=3.54, SD=0.42, t(74)=11.11, p=0.00, d=1.29). Conversely, in cluster 2 (n=18), there was no association between teachers' attitudes towards, interest about and importance given to biotechnology (p>0.05), and from these dimensions, teachers' interest about biotechnology was the only one significantly, and strongly, correlated with the importance given to biotechnology education (r_s=0.60, *n*=93, *p*=0.01). Considering Ryan and Deci's (2000) argument that intrinsic motivation reflects a natural propensity towards an object, whereas extrinsic motivation can reflect external control, these outcomes demonstrate that some teachers are naturally driven to acknowledge the importance of biotechnology education (cluster 2), while for others there is also a contribution of external inputs (cluster 1). Moreover, the results also indicate that these intrinsic and extrinsic motivational features can have a greater impact on teachers' beliefs about the importance of biotechnology education than their attitudes towards the subject itself. Nevertheless, in spite of the specificities of teachers' beliefs within each cluster, these did not translate into relevant differences concerning their perception of the limitations posed at biotechnology teaching and the frequency with which they engage in behaviours to improve their practice (*Supporting information – Fig. IV.S4*).

Effect of teachers' general features on their beliefs

Since teachers' beliefs are structured throughout their practicing experience (Gess-Newsome, 1999; Özgün-Koca & Ilhan Sen, 2006), it is important to understand how those beliefs are affected by their age, teaching experience, qualifications, and training background. Having in mind the heterogeneity of the study sample concerning these general features, teachers' profiles could be expected to be associated with different belief patterns. However, contrary to this assumption, they were not significantly associated (*p*>0.05) with cluster membership, nor with teachers' responses to individual and composite variables, except for a few discrete situations (*Supporting information – Table IV.S2*).

Concerning teachers age, there was a tendency for older teachers to find themselves less informed about biotechnology than younger teachers (r_s=-0.23, *n*=90, *p*=0.03), and to emphasize the lack of materials and infrastructures in schools (r_s=-0.24, *n*=90, *p*=0.02). However, there were no major age-related differences in teachers beliefs about biotechnology, which is not surprising, considering that the oldest respondent was 59 years old and that the significance of age in public opinion surveys on biotechnology has been reported to manifest when comparing age groups below and above 65 years old (Gaskell et al., 2006).

It was surprising to notice that there were no significant differences related with teaching experience (in general and in 12th grade biology), qualifications and complementary training in biotechnology (p>0.05). According to the literature, more and less experienced teachers tend to act similarly when addressing contents in which they are not experts (Sanders, Borko, & Lockard, 1993). Consistently with these reports, although the participants were confident about their competencies to teach biotechnology, it can be argued that they may not master the subject. The lack of significant differences between teachers with and without experience in teaching 12th grade biology, may also result from the relatively recent implementation, in 2004/2005, of the current curriculum covering biotechnology topics, which replaced a curriculum more oriented towards classic biology, without a specific emphasis on technology and applicability. So, even teachers who had taught 12th grade biology might have a limited experience in teaching biotechnology-related contents.

Also unexpected and seemingly contradictory was the absence of a significant effect associated with teachers' training experience. Particularly since the respondents mentioned that they were interested in receiving complementary training on biotechnology. A possible explanation for this relates to the effectiveness of the complementary training that these teachers received. In fact, although 11 teachers attended biotechnology-related continuing training, only two of them mentioned that the courses were specifically focused on biotechnology procedures (*Supporting information – Fig. IV.S2*). The other nine teachers attended workshops tackling biotechnology in a broader sense, by addressing molecular biology and genetics contents. Another aspect to account for, is how teachers select their training and the implications of this selection. Teachers may choose to attend courses that interest them or that give them the credits required for their career progression, but that do not necessarily provide them with renewed and increased competencies on specific topics. If this was the case with some of the respondents, it is possible that the extent of their learning and the nature of their experiences did not foster measurable differences in their beliefs about biotechnology and biotechnology education.

Conclusions

According to the conceptual framework defined, teachers' engagement is influenced by their beliefs about biotechnology and biotechnology education, which act as endogenous factors, and also by exogenous factors related with elements that impact on their practice regardless of their beliefs. In light of this framework, teachers' exacerbated assessment of the insufficiency or inadequacy of materials in schools and unavailability of educational resources seems to have a greater impact on their practice than the actual practical limitations they encounter, and their beliefs about biotechnology. This study reveals that teachers' beliefs about the subject itself, their competencies to address it and the students' response to it, are not necessarily detrimental of their practice. Instead, teachers denoted some difficulties in coping with the additional effort necessary to overcome obstacles raised by biotechnology education, which demands the improvement of their information management skills. In fact, teachers' responses reflected a limited awareness of available educational resources that can be related with their tendency to restrict their search for information to a small number of sources. Nevertheless, they were receptive and eager for more information and increased training opportunities, which is an encouraging starting point to devise adapted interventions.

Implications for teacher education and research

This study has implications for teacher education as it evidences the need to improve teachers' competencies in searching, selecting, and adapting information for classroom instruction. Teacher training programs should be developed and implemented as part of teachers' preservice and inservice education. In addition to informative actions and teacher meetings to acquaint teachers with the countless resources that they can easily access, more complex interventions to instruct them to adapt those resources according to the specificities of their students and schools should be organised at national levels by the Ministry of Education or at local levels by teacher associations and other institutions. Currently in Portugal, some Sciences Faculties and Research Institutes organise credited biology-oriented courses and workshops. A way to meet teachers' demands for more certified training would be to increase the frequency of these events in order to provide teachers with regular continuing training about biotechnology. These courses should be oriented to purposely address curriculum-related competencies, namely by favouring practical procedures that enable teachers to improve the development of their own activities or adaptation of existing ones. For instance, alternative strategies involving the use of simulations, animations, and the discussion of ethical dilemmas, among others, can be used to explore the conceptual frameworks underlying many laboratory activities that the lack of specialised settings and materials in schools prevents from being implemented. Moreover, teachers' creativity can be prompt by highlighting alternative protocols. In fact, the insights provided by this study were used to design a set of practical activities contextualised in the 12th grade biology curriculum that require inexpensive and easily available materials and equipment and that are accessible even for teachers who are inexperienced in practical work (Fonseca & Tavares, 2011a,b). The validation of these activities is currently being conducted through their classroom implementation by a group of 12th grade biology teachers.

Beyond the implications for biotechnology education, this study provides a framework for research on other science topics, such as global warming or nuclear energy utilisation, that also demand teachers to adopt innovative strategies and mobilize multidisciplinary knowledge. In addition, by making available a new instrument specifically designed to assess the interaction between teachers' beliefs about biotechnology and biotechnology teaching, this study paves the way for further qualitative research projects that can contribute to strengthen the robustness of the indicators presented. Since the generalisation of these findings to teacher populations in other countries may not be straightforward (Cohen, Manion, & Morrison, 2007), it would be interesting to extend this study to countries in which biotechnology topics have been integrated in science curricula, as for instance the USA, UK, Turkey, Israel, New Zealand and Australia, (Falk et al., 2008; Hanegan & Bigler, 2009; Steele & Aubusson, 2004; Usak et al., 2009). By considering the socio-cultural specificities, educational models, resourcefulness of each country, and the influence that these elements exert on teachers' beliefs it would be possible to conduct a broader, more comprehensive identification of elements required to improve the efficiency of biotechnology education. Of particular interest would be to evaluate the quality and outcomes of teacher-oriented biotechnology-related training in order to understand how currently available teacher-training courses contribute to improved biotechnology teaching.

Therefore, this work can inspire new research questions, namely concerning: teachers' affective response to biotechnology; the impact of specific features of teacher populations, related with the structure and contents of pre- and inservice teacher education systems; the use they make of materials produced by others; and the impact of teacher training programs, for instance by tracking how teachers apply the information made available to them in their practice. Given that the ultimate aim of teacher education is to improve teaching to enhance students' learning, future research should also invest in assessing the effects of teachers' beliefs about biotechnology and biotechnology education on their students' own beliefs and understandings.

Acknowledgements

The authors are grateful to all the teachers who participated in this study and to Catarina L. Santos for helpful comments and suggestions on the manuscript. MJF is supported by the FCT fellowship SFRH/BD/37389/2007.

References

Aiken, L. R. (2002). *Attitudes and related psychosocial constructs. Theories, assessment, and research*. Thousand Oaks, CA: Sage Publications, Inc.

Akerson, V. L., Morrison, J. A., & McDuffie, A. R. (2006). One course is not enough: Preservice elementary teachers' retention of improved views of nature of science. *Journal of Research in Science Teaching, 43*(2), 194-213.

Babbie, E. R. (2008). *The basics of social research*. Belmont, CA: Thomson Wadsworth.

Bennett, J., Lubben, F., & Hogarth, S. (2007). Bringing science to life: A synthesis of the research evidence on the effects of context-based and STS approaches to science teaching. *Science Education, 91*(3), 347-370.

Brossard, D., & Nisbet, M. C. (2007). Deference to scientific authority among a low information public: Understanding U.S. opinion on agricultural biotechnology. *International Journal of Public Opinion Research, 19*(1), 24-52.

Bryan, L. A., & Atwater, M. M. (2002). Teacher beliefs and cultural models: A challenge for science teacher preparation programs. *Science Education, 86*(6), 821-839.

Bryce, T., & Gray, D. (2004). Tough acts to follow: The challenges to science teachers presented by biotechnological progress. *International Journal of Science Education, 26*, 717-733.

Cabo Hernández, J. M., Enrique Mirón, C., & Cortiñas Jurado, J. R. (2006). Opiniones e intenciones del professorado sobre la participatión social en ciencia y tecnologia. El caso de la biotecnologia. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias, 3*(3), 349-369.

Chen, S.-Y., & Raffan, J. (1999). Biotechnology: Student's knowledge and attitudes in the UK and Taiwan. *Journal of Biological Education, 34*, 17-23.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. New Jersey: Lawrence Erlbaum

Cohen, L., Manion, L., & Morrison, K. (2007). *Research methods in education* (6th ed.). London, New York: Routledge Falmer.

Costa-Font, M., Gil, J. M., & Traill, W. B. (2008). Consumer acceptance, valuation of and attitudes towards genetically modified food: Review and implications for food policy. *Food Policy, 33*(2), 99-111.

Costello, A. B., & Osborne, J. W. (2005). Best practices in exploratory factor analysis: Four recommendations for getting the most from your analysis. *Practical Assessment, Research and Evaluation, 10*(7).

David, M., & Sutton, C. D. (2004). *Social research: The basics*. London: SAGE.

Dawson, V. (2007). An exploration of high school (12–17 year old) students' understandings of, and attitudes towards biotechnology processes. *Research in Science Education, 37*(1), 59-73.

De Vaus, D. A. (2002). *Surveys in social research*. London: Routledge.

Direcção-Geral de Inovação e Desenvolvimento Curricular (2004). *Programa de Biologia 12º ano*. Lisboa: Ministério da Educação.

Duke, T. S., & Ward, J. D. (2009). Preparing information literate teachers: A metasynthesis. *Library & Information Science Research, 31*(4), 247-256.

Einsiedel, E., Premji, S., Geransar, R., Orton, N., Thavaratnam, T., & Bennett, L. (2009). Diversity in public views toward stem cell sources and policies. *Stem Cell Reviews and Reports, 5*(2), 102-107.

Falk, H., Brill, G., & Yarden, A. (2008). Teaching a biotechnology curriculum based on adapted primary literature. *International Journal of Science Education, 30*(14), 1841-1866.

Fonseca, M. J., & Tavares, F. (2011a). Natural antibiotics: a hands-on activity on garlic's antibiotic properties. *American Biology Teacher*, *73*(6), 342-346.

Fonseca, M. J., & Tavares, F. (2011b). The bactericidal effect of sunlight. *American Biology Teacher*, *73*(9), 548-552.

France, B. (2007). Location, location, location: Positioning biotechnology education for the 21st Century. *Studies in Science Education, 43*(1), 88-122.

Gaskell, G., Stares, S., Allansdottir, A., Allum, N., Corchero, C., Fischler, C., …Wagner, W. (2006). *Europeans and biotechnology in 2005: Patterns and trends. Final report on Eurobarometer 64.3*. European Commission: Research Directorate-General.

Gess-Newsome, J. (1999). Secondary teachers' knowledge and beliefs about subject matter and their impact on instruction. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining Pedagogical Content Knowledge* (pp. 51-94). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Gravetter, F. J., & Forzano, L. B. (2009). *Research methods for the behavioral sciences* (3rd ed.). Belmont, CA: Wadsworth Cengage Learning.

Guion, R. M., & Highhouse, S. (2006). *Essentials of personnel assessment and selection*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Hanegan, N., & Bigler, A. (2009). Infusing authentic inquiry into biotechnology. *Journal of Science Education and Technology, 18*(5), 393-401.

Hayton, J. C., Allen, D. G., & Scarpello, V. (2004). Factor retention decisions in exploratory factor analysis: A tutorial on parallel analysis. *Organizational Research Methods, 7*(2), 191-205.

Henson, R.K., & Roberts, J.K. (2006). Use of exploratory factor analysis in published research: Common errors and some comment on improved practice. *Educational and Psychological Measurement, 66*, 393-416.

Hill, T., & Lewicki, P. (2006). *Statistics: Methods and applications: A comprehensive reference for science, industry, and data mining*. Tulsa. OK: StatSoft.

Ho, R. (2006). *Handbook of univariate and multivariate data analysis and interpretation with SPSS*. Boca Raton, FL: Taylor & Francis Group.

Hofstein, A., & Lunetta, V. N. (2003). The laboratory in science education: Foundations for the twenty-first century. *Science Education, 88*(1), 28-54.

Keil, R. L., & Palmer, L. K. (2009). A visual demonstration of plasmid DNA preparation from bacteria. *American Biology Teacher, 71*(6), 363-366.

Kidman, G. (2009). Attitudes and interests towards biotechnology: The mismatch between students and teachers. *Eurasia Journal of Mathematics, Science & Technology Education, 5*(2), 135-143.

Klop, T., & Severiens, S. (2007). An exploration of attitudes towards modern biotechnology: A study among Dutch secondary school students. *International Journal of Science Education, 29*(5), 663-679.

MacCallum, R. C., Widaman, K. F., Zhang, S. B., & Hong, S. H. (1999). Sample size in factor analysis. *Psychological Methods, 4*(1), 84-99.

Macer, D. R. J., Asada, Y., Tsuzuki, M., Akiyama, S., & Macer, N. Y. (1996). *Bioethics in high schools in Australia, Japan & New Zealand*. Ibaraki: Institute of Biological Sciences, University of Tsukuba.

Maruish, M. E. (Ed.). (1999). *The use of psychological testing for treatment planning and outcomes assessment* (2nd ed. Vol. 3). London: Routledge.

Miles, S., Ueland, Oslash, Øydis, & Frewer, L. J. (2005). Public attitudes towards genetically-modified food. *British Food Journal, 107*, 246-262.

Milne, C., & Morrison, A. (2007). Demystifying biotechnology: The PCR game. *Teaching Science, 53*(1), 19-23.

Nespor, J. K. (1985). *The role of beliefs in the practice of teaching: Final report of the teacher belief study*. Texas University, Austin.

Nisbet, M. C. (2004). Public opinion about stem cell research and human cloning. *Public Opinion Quarterly, 68*(1), 131-154.

Oppenheim, A. N. (1992). *Questionnaire design, interviewing and attitude measurement* (New ed.). London, New York: Continuum.

Özgün-Koca, S. A., & Ilhan Sen, A. (2006). The beliefs and perceptions of pre-service teachers enrolled in a subject-area dominant teacher education program about "Effective Education". *Teaching and Teacher Education, 22*(7), 946-960.

Pajares, M. F. (1992). Teachers' beliefs and educational research: Cleaning up a messy construct. *Review of Educational Research, 62*(3), 307-332.

Pardo, R., Midden, C., & Miller, J. D. (2002). Attitudes toward biotechnology in the European Union. *Journal of Biotechnology, 98*, 9-24.

Richardson, V. (2003). Preservice teachers' beliefs. In J. Raths & A. R. McAninch (Eds.), *Teacher beliefs and classroom performance: The impact of teacher education.* . Greenwich, Connecticut: Information Age Publishing: Information Age Pub.

Rosenberg, M. J., & Hovland, C. I. (1960). Cognitive, affective, and behavioral components of attitudes. In C. I. Hovland & M. J. Rosenberg (Eds.), *Attitude organization and change: An analysis of consistency among attitude components* (pp. 1-14). New Haven, CT: Yale University Press.

Rothhaar, R., Pittendrigh, B. R., & Orvis, K. S. (2006). The Lego® analogy model for teaching gene sequencing and biotechnology. *Journal of Biological Education, 40* (4), 166-171.

Ryan, R. M., & Deci, E. L. (2000). Intrinsic and extrinsic motivations: Classic definitions and new directions. *Contemporary Educational Psychology, 25*(1), 54-67.

Sáez, M. J., Niño, A. G., & Carretero, A. (2008). Matching society values: Students' views of biotechnology. *International Journal of Science Education, 30*(2), 167 - 183.

Sanders, L. R., Borko, H., & Lockard, J. D. (1993). Secondary science teachers' knowledge-base when teaching science courses in and out of their area of certification. *Journal of Research in Science Teaching, 30*(7), 723-736.

Sharma, S. (1996). *Applied multivariate techniques*. New York: Jonh Wiley & Sons, Inc.

Siti Hendon, S. A., & Khalijah, M. S. (2007). Science teaching for enlightment: A holistic approach in developing a teachers' guide for best practices to teach at secondary level. *Asia-Pacific Forum on Science Learning and Teaching, 8*(1).

Šorgo, A., & Ambrožič-Dolinšek, J. (2010). Knowledge of, attitudes toward, and acceptance of genetically modified organisms among prospective teachers of biology, home economics, and grade school in Slovenia. *Biochemistry and Molecular Biology Education, 38*(3), 141-150.

Steele, F., & Aubusson, P. (2004). The challenge in teaching biotechnology. *Research in Science Education, 34*, 365-387.

Sun, H., & Liu, T. (2009). Cultivation of science teachers' information literacy in China. *International Education Studies, 2*(3), 147-150.

Twisk, J., & de Vente, W. (2002). Attrition in longitudinal studies - How to deal with missing data. *Journal of Clinical Epidemiology, 55*, 329-337.

Usak, M., Erdogan, M., Prokop, P., & Ozel, M. (2009). High school and university students' knowledge and attitudes regarding biotechnology. *Biochemistry and Molecular Biology Education, 37*(2), 123-130.

Van Driel, J. H., Beijaard, D., & Verloop, N. (2001). Professional development and reform in science education: The role of teachers' practical knowledge. *Journal of Research in Science Teaching, 38*(2), 137-158.

Van Driel, J. H., Bulte, A. M. W., & Verloop, N. (2007). The relationships between teachers' general beliefs about teaching and learning and their domain specific curricular beliefs. *Learning and Instruction, 17*(2), 156-171.

Wallace, C. S., & Kang, N. H. (2004). An investigation of experienced secondary science teachers' beliefs about inquiry: An examination of competing belief sets. *Journal of Research in Science Teaching, 41*(9), 936-960.

Wasserman, J. D., & Bracken, B. A. (2003). Psychometric characteristics of assessment procedures. In J. A. N. J. R. Graham (Ed.), *Handbook of Psychology: Assessment psychology* (Vol. Vol. 10, pp. pp. 43-66). Hoboken, NJ: John Wiley & Sons, Inc.

Williams, D., & Coles, L. (2007). Teachers' approaches to finding and using research evidence: An information literacy perspective. *Educational Research, 49*(2), 185-206.

Wilson, E., Kirby, B., & Flowers, J. (2002). Factors influencing the intent of North Carolina agricultural educators to adopt agricultural biotechnology curriculum. *Journal of Agricultural Education, 43*(1), 69-81.

Worthington, R. L., & Whittaker, T. A. (2006). Scale development research: A content analysis and recommendations for best practices. *The Counseling Psychologist, 34*(6), 806-838.

Zeidler, D. L., Sadler, T. D., Simmons, M. L., & Howes, E. V. (2005). Beyond STS: A research-based framework for socioscientific issues education. *Science Education, 89*(3), 357-377.

Appendix IV.A1

Questionnaire used in the study.

The items were translated to English from the original version administered in the respondents' native language.

Part I

Please indicate: age; gender; years of service; academic degree(s); name of the course(s) attended; name of the higher education institution(s) attended; subjects taught; if applicable, name and duration of complementary training programs attended.

Part II

Q1 How important do you think biotechnology is to the quality of life (1-Not at all important to 5-Very important)?

Q2 Rate your approval towards the following activities (1-I do not approve it at all to 5-I approve it completely).
(a) Use of yeast in the production of bread, wine and beer; (b) Use of yeast in animal food production; (c) Use of GM microorganisms in waste treatment; (d) Plant growth improvement in saline environments by gene alteration; (e) Treatment of genetic disorders by embryonic gene manipulation; (f) Treatment of genetic disorders by human gene manipulation; (g) Insertion of plant genes into animals; (h) Use of GM cows in the production of medicines for humans; (i) Production of pesticide resistant plants by gene manipulation; (j) Genetic modification of tomatoes to make them ripen more slowly and have a longer shelf life; (k) Use of insulin produced by bacteria; (l) Organ transplant from transgenic animals to humans; (m) Use of human cloning for therapeutic purposes; (n) Use of human cloning with reproductive purposes.

Q3 Rate your agreement with the following sentences (1-I totally disagree to 5-I totally agree).
(a) It is our duty to authorise investigation that may lead to the development of more efficient medical treatments, even if it implies using embryonic stem cells; (b) The labels of transgenic foods should specify whether the food or any of its ingredients is genetically modified; (c) Future generations will benefit from biotechnology's medical applications; (a') It is wrong to use embryonic stem cells in biomedical research, even if it may contribute to the development of medical treatments; (d) Each of us is capable of determining our intake of transgenic foods.

Q4 How often would you… (1-Never to 5-Always)
(a) …buy transgenic foods if they were easily available in supermarkets; (b) …buy medicines obtained by genetic manipulation; (c)) …do a genetic test for medical diagnostic; (d) …give the police access to your genetic information; (e) …buy transgenic foods if they were healthier than other foods?

Q5 Rate your interest towards biotechnology (1-I am not interested at all to 5-I am very interested).

Q6 How well informed are you about biotechnology (1-Not at all informed to 5-Very well informed)?

Q7 From which of the following sources do you most commonly obtain information about biotechnology?
TV; Radio; Newspapers, Magazines; Training programs; Scientific magazines; Internet; Textbooks; Scientific papers; Workshops; Conferences; Exhibitions; Friends and colleagues; Others.

Q8 Rate your trust in the following sources of information about biotechnology (1-I do not trust it/them at all to 5-I trust it/them completely): (a) Media; (b) Scientific magazines; (c) Pharmaceutical industry; (d) Agro-food industry; (e) Health industry; (f) Governmental agencies; (g) Universities; (h) Scientists; (i) Internet; (j) Environmental organisations; (k) Consumer rights organisations; (l) European Union; (m) Medical doctors; (n) Politicians.

Q9 How important do you think biotechnology education is (1-Not at all important to 5-Very important)?

Q10 Rate your agreement with the following sentences (1-I totally disagree to 5-I totally agree).
(a) My academic training allows me to address biotechnology related issues in the classroom; (b) Students are interested in biotechnology; (c) Planning classes addressing biotechnology contents requires more work than preparing other classes[r]; (d) Developing activities about biotechnology is more time consuming than developing other type of activities[r]; (e) The availability of complementary training in biotechnology is insufficient; (f) School textbooks coverage of biotechnology is sufficient; (g) The information about biotechnology available in school textbooks is scientifically supported; (h) Students understand easily biotechnology related subjects; (i) Biotechnology is adequately addressed in the 12th grade biology curriculum; (j) Students' scientific literacy regarding biotechnology is adequately assessed in a national exam in the end of the secondary school cycle; (k) There are enough educational resources about biotechnology available for teachers; (l) The ethical aspects involved in biotechnology should be addressed in the classroom; (m) Schools have adequate settings for the development of activities about biotechnology; (n) Schools have adequate resources for the development of activities about biotechnology; (o) There are enough educational resources about biotechnology available for students; (p) The existent educational resources about biotechnology are student-friendly; (q) The duration of 12th grade biology classes allows the development of activities about biotechnology.

Q11 How often do you… (1-Never to 5-Many times)
(a) … use information sources about biotechnology to keep up-to-date; (b) …ask universities for collaboration in preparing classes about biotechnology; (c) …contact experts in the field of biotechnology to give lectures in the school; (d) …attend conferences about biotechnology; (e)… participate in training courses about biotechnology; (f) …organise visits to non-formal education contexts (for instance science centres or open days at universities) to promote biotechnology education?

Q12 Are you interested in implementing experimental activities in the scope of biotechnology in the classes you teach (Yes/No)?

Q13 Are you interested in participating in training courses in the scope of formal biotechnology education (Yes/No)?

(a')- internal check item. r - reversed items.

Supporting information

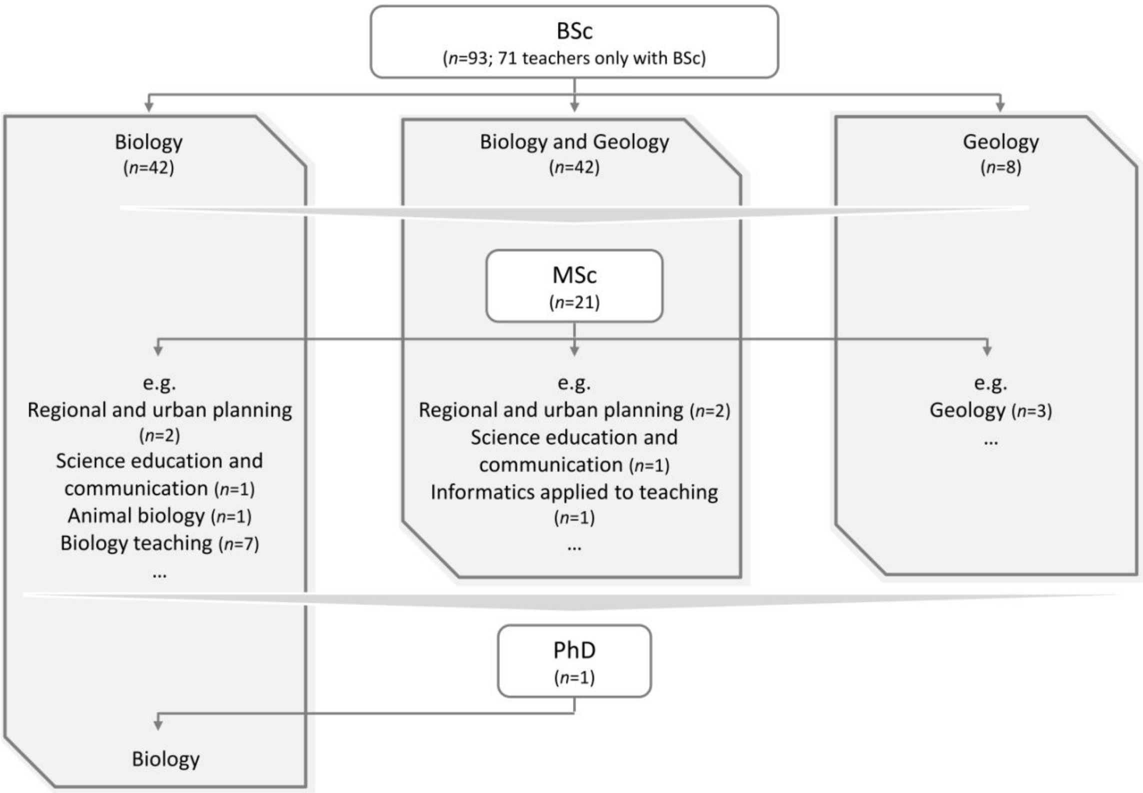
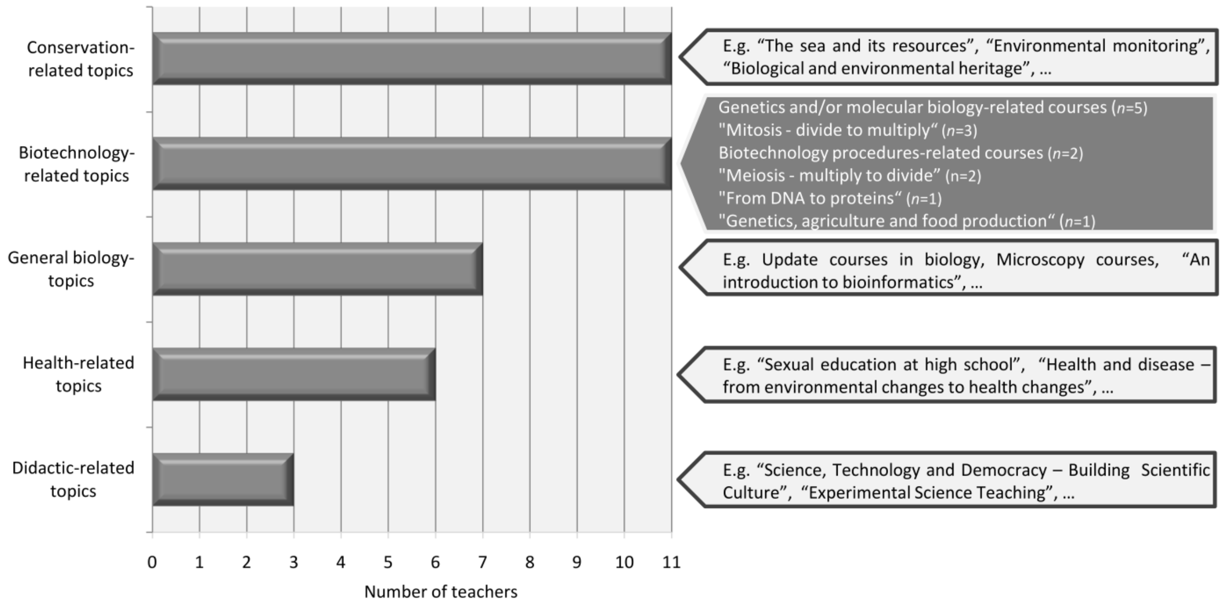


Fig. IV.S1. Teachers' initial training and qualifications.



The results refer to the frequency of teachers who reported to have attained continuing training (n=26). Examples of courses mentioned by the teachers are provided for all categories, except for *biotechnology-related topics*, for which a complete list is presented (highlighted in grey).

Fig. IV.S2. Teachers' complementary training in biology and biology teaching.

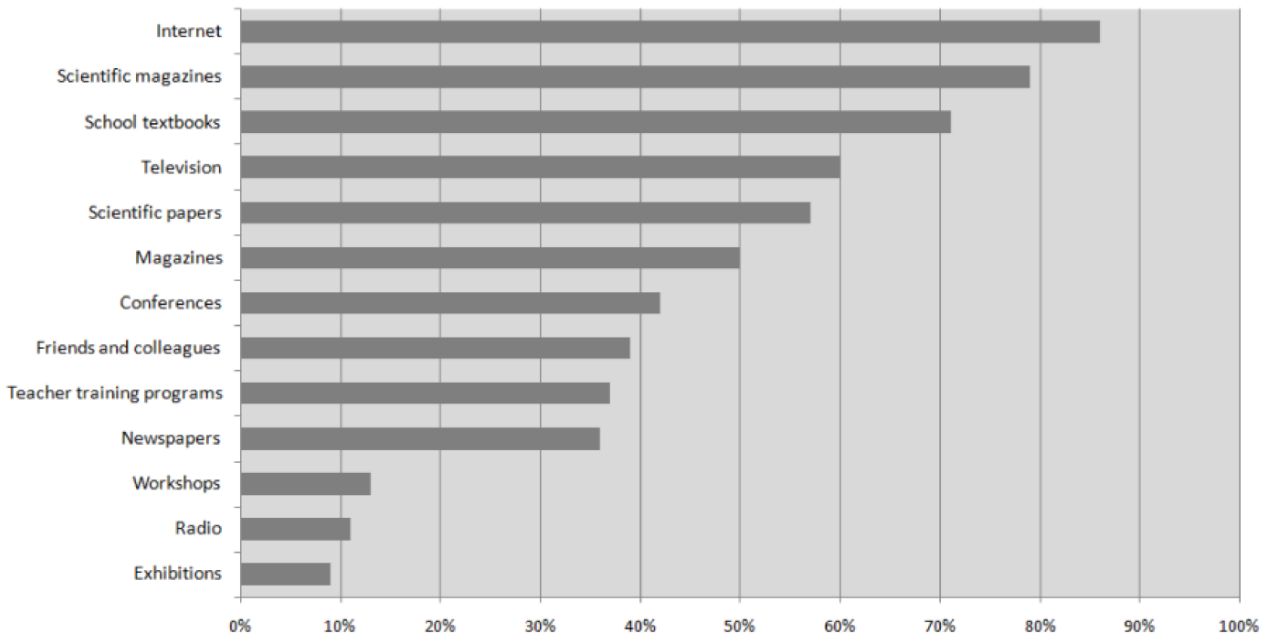


Fig. IV.S3. Information sources about biotechnology used by teachers.

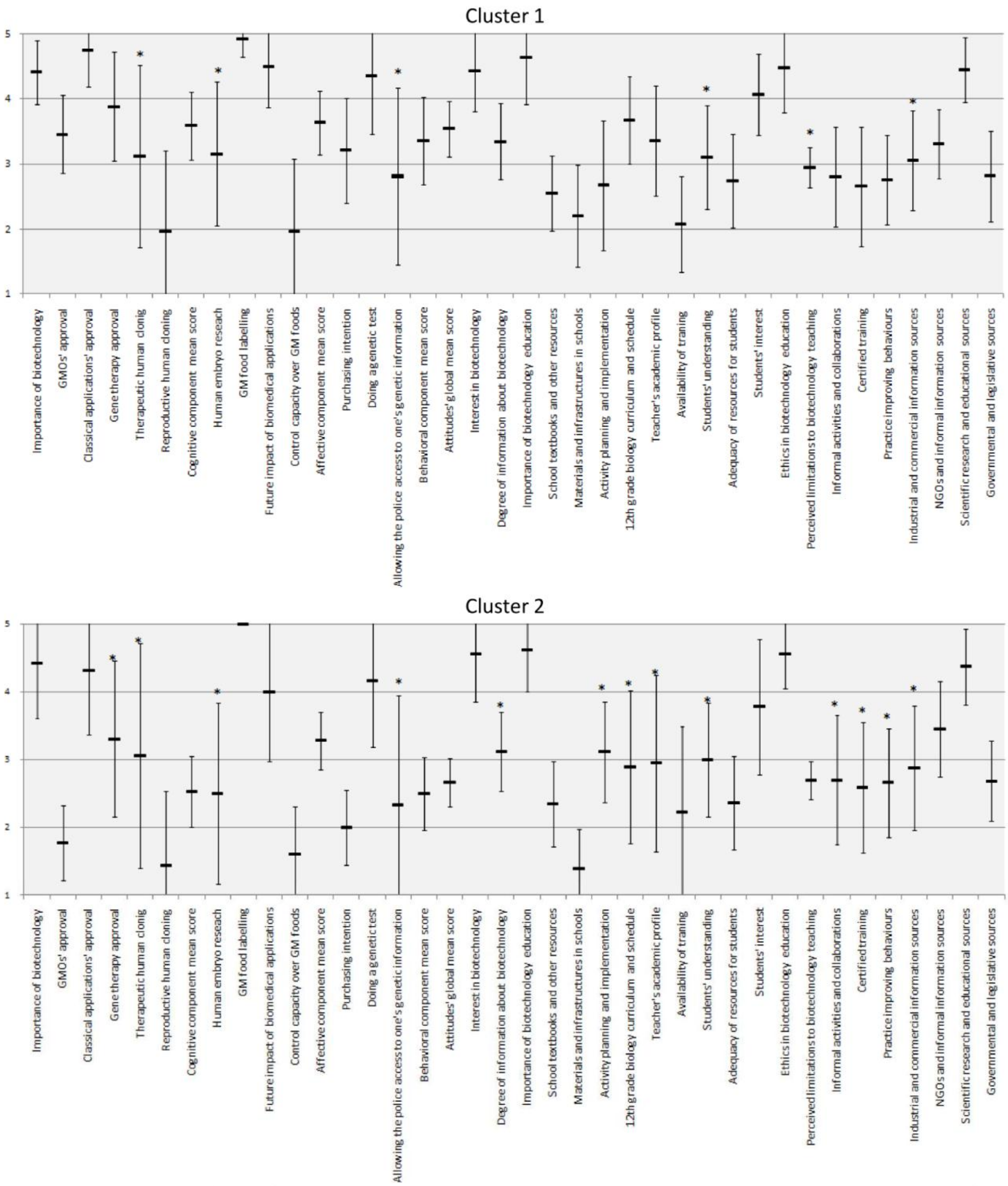


Fig. IV.S4. Teachers' beliefs about biotechnology and biotechnology teaching and trust in sources of information, according to the clusters identified by hierarchical cluster analysis (Ward's method, squared Euclidean measure of distance).

Cluster 1 - *n*=75 (81%), cluster 2 - *n*=18 (19%). *indicates mean scores that are not significantly different from 3, for α=0.05. The full description of the items and factors displayed is available in Appendix IV.1 and Tables IV.2 to IV.6.

Table IV.S1
Description of the study sample (*n*=93).

FEATURE	OPTION	NUMBER	PERCENTAGE
Age	25-30	22	24%
	31-35	9	10%
	36-40	9	10%
	41-45	21	23%
	4-50	17	18%
	51-55	9	10%
	56-59	3	3%
	No answer	3	3%
Gender	Female	78	84%
	Male	15	16%
Teaching experience	Less than 18 years	42	45%
	18 or more years	49	53%
	No answer	2	2%
Experience teaching 12th grade biology	Yes	59	63%
	No	33	36%
	No answer	1	1%
Qualifications (academic degree)	BSc	71	76%
	MSc	21	23%
	PhD	1	1%
Initial training background	Biology	42	45%
	Biology and Geology	42	45%
	Geology	8	9%
	No answer	1	1%
Complementary training in biology (e.g. laboratory work, didactics and specific procedures)	Yes	26	28%
	No	56	60%
	No answer	11	12%
Complementary training in biotechnology-related topics and methods	Yes	11	12%
	No	15	16%

Table IV.S2

Correlations between teachers' profile and their beliefs about biotechnology and biotechnology education.

		AGE		GENDER	TEACHING EXPERIENCE	EXPERIENCE TEACHING 12^{TH} GRADE BIOLOGY	QUALIFICATIONS	INITIAL TRAINING BACKGROUND	COMPLEMENTARY TRAINING IN BIOLOGY	COMPLEMENTARY TRAINING IN BIOTECHNOLOGY
Cluster membership	χ^2	6.24		0.42	0.59	0.06	4.06	2.89	1.54	2.99
	df	6		1	1	1	2	2	1	1
	p	0.40		0.52	0.44	0.80	0.13	0.24	0.21	0.08
	V/Ø	0.26		-0.07	0.08	0.03	0.21	0.18	0.14	0.18
	p	0.40		0.52	0.44	0.80	0.13	0.24	0.21	0.08
Importance of biotechnology (Q1)	r_s	-0.06	χ^2	4.18	6.96	2.73	5.34	7.76	2.64	0.88
	n	90	df	4	4	4	8	8	3	4
	p	0.60	*p*	0.38	0.14	0.60	0.72	0.46	0.45	0.93
			V/Ø	0.21	0.28	0.17	0.17	0.21	0.18	0.10
			p	0.38	0.14	0.60	0.72	0.46	0.45	0.93
GMOs approval (Q2c, Q2d, Q2g, Q2h, Q2i, Q2j)	r_s	-0.06	χ^2	22.95	26.92	21.99	28.05	40.72	27.39	24.29
	n	90	df	26	26	26	52	52	25	26
	p	0.58	*p*	0.64	0.41	0.69	1.00	0.87	0.34	0.56
			V/Ø	0.50	0.54	0.49	0.39	0.47	0.59	0.51
			p	0.64	0.41	0.69	1.00	0.87	0.34	0.56
Classical applications approval (Q2a, Q2b)	r_s	0.04	χ^2	3.53	12.59	15.07	8.77	12.48	4.27	2.59
	n	90	df	8	8	8	16	16	8	8
	p	0.69	*p*	0.90	0.13	0.06	0.92	0.71	0.83	0.96
			V/Ø	0.20	0.37	0.41	0.22	0.26	0.23	0.17
			p	0.90	0.13	0.06	0.92	0.71	0.83	0.96
Gene therapy approval (Q2e, Q2f)	r_s	0.06	χ^2	12.43	10.36	0.70	18.21	12.08	4.87	4.94
	n	90	df	8	8	8	16	16	8	8
	p	0.56	*p*	0.13	0.24	0.29	0.31	0.74	0.77	0.76
			V/Ø	0.37	0.34	0.33	0.31	0.26	0.24	0.23
			p	0.13	0.24	0.29	0.31	0.74	0.77	0.76
Therapeutic human cloning (Q2m)	r_s	0.05	χ^2	2.83	3.03	7.46	**17.32**	13.81	1.82	2.27
	n	90	df	4	4	4	**8**	8	4	4
	p	0.67	*p*	0.59	0.55	0.11	**0.03**	0.09	0.77	0.69
			V/Ø	0.17	0.18	0.29	**0.31**	0.27	0.15	0.16
			p	0.59	0.55	0.11	**0.03**	0.09	0.77	0.69
Reproductive human cloning (Q2n)	r_s	-0.11	χ^2	7.28	1.42	**11.54**	3.27	6.33	3.32	2.73
	n	90	df	4	4	**4**	8	8	4	4
	p	0.32	*p*	0.12	0.84	**0.02**	0.92	0.61	0.51	0.61
			V/Ø	0.28	0.12	**0.34**	0.13	0.19	0.20	0.17
			p	0.12	0.84	**0.02**	0.92	0.61	0.51	0.61

Age - seven ranks, 25-59 years old. Teaching experience - above/below 18 years. Experience teaching 12^{th} grade - Yes/No. Qualifications - BSc, MSc, PhD. Initial training background - Biology and/or Geology. Complementary training in biology/biotechnology - Yes/No. r_s - Spearman's rank correlation coefficient. *Ø* - Pearson's Phi. *V* - Cramér's V. df - degrees of freedom. Tests performed for a 95% confidence interval. Significant results are highlighted in bold.

Table IV.S2 (continued)

		Age		Gender	Teaching experience	Experience teaching 12th grade biology	Qualifications	Initial training background	Complementary training in biology	Complementary training in biotechnology
Attitudes' cognitive component (Q2)	r_s	-0.04	χ^2	36.20	29.35	38.47	52.67	64.32	32.55	33.56
	n	90	df	33	32	33	66	66	31	33
	p	0.71	p	0.32	0.60	0.24	0.88	0.54	0.39	0.44
			$V/Ø$	0.62	0.57	0.65	0.53	0.59	0.63	0.60
			p	0.32	0.60	0.24	0.88	0.54	0.39	0.44
Human embryo research (Q3a)	r_s	-0.10	χ^2	5.12	2.23	5.62	10.97	3.21	7.40	1.98
	n	90	df	4	4	4	8	8	4	4
	p	0.33	p	0.28	0.69	0.23	0.20	0.92	0.12	0.74
			$V/Ø$	0.24	0.16	0.25	0.24	0.13	0.30	0.15
			p	0.28	0.69	0.23	0.20	0.92	0.12	0.74
GM food labelling (Q3b)	r_s	0.10	χ^2	0.00	1.09	0.56	0.48	0.74	1.97	0.14
	n	90	df	1	1	1	2	2	1	1
	p	0.34	p	0.97	0.30	0.46	0.79	0.69	0.16	0.70
			$V/Ø$	0.00	0.11	0.08	0.07	0.09	-0.16	-0.04
			p	0.97	0.30	0.46	0.79	0.69	0.16	0.70
Future impact of biomedical applications (Q3c)	r_s	-0.08	χ^2	4.94	1.83	5.02	4.28	3.41	3.21	7.38
	n	90	df	3	3	3	6	6	3	3
	p	0.48	p	0.18	0.61	0.17	0.64	0.76	0.36	0.06
			$V/Ø$	0.23	0.14	0.23	0.15	0.14	0.20	0.28
			p	0.18	0.61	0.17	0.64	0.76	0.36	0.06
Control capacity over GM foods (Q3e)	r_s	**-0.23**	χ^2	6.59	8.90	**10.36**	8.01	8.96	5.42	1.84
	n	**90**	df	4	4	**4**	8	8	4	4
	p	**0.03**	p	0.16	0.06	**0.04**	0.43	0.35	0.25	0.77
			$V/Ø$	0.27	0.31	**0.34**	0.21	0.22	0.26	0.14
			p	0.16	0.06	**0.04**	0.43	0.35	0.25	0.77
Attitudes' affective component (Q3)	r_s	-0.20	χ^2	14.30	12.83	14.54	11.73	15.91	16.84	4.70
	n	90	df	10	10	10	20	20	9	10
	p	0.06	p	0.16	0.23	0.15	0.92	0.72	0.05	0.91
			$V/Ø$	0.39	0.38	0.40	0.25	0.29	0.45	0.22
			p	0.16	0.23	0.15	0.92	0.72	0.05	0.91
Purchasing intention (Q4a, Q4b, Q4e)	r_s	-0.08	χ^2	12.85	8.15	14.06	33.60	21.76	9.55	14.46
	n	90	df	12	12	12	24	24	12	12
	p	0.46	p	0.38	0.77	0.30	0.09	0.59	0.66	0.27
			$V/Ø$	0.37	0.30	0.39	0.43	0.34	0.34	0.39
			p	0.38	0.77	0.30	0.09	0.59	0.66	0.27

Age - seven ranks, 25-59 years old. Teaching experience - above/below 18 years. Experience teaching 12th grade - Yes/No. Qualifications - BSc, MSc, PhD. Initial training background - Biology and/or Geology. Complementary training in biology/biotechnology - Yes/No. r_s - Spearman's rank correlation coefficient. Ø - Pearson's Phi. V - Cramér's V. df - degrees of freedom. Tests performed for a 95% confidence interval. Significant results are highlighted in bold.

Table IV.S2 (continued)

		Age		Gender	Teaching experience	Experience teaching 12^{th} grade biology	Qualifications	Initial training background	Complementary training in biology	Complementary training in biotechnology
Doing a genetic test (Q4c)	r_s	-0.09	χ^2	7.65	1.74	0.87	4.88	6.63	3.75	1.68
	n	90	df	4	4	4	8	8	4	4
	p	0.41	*p*	0.11	0.78	0.93	0.77	0.58	0.44	0.80
			V/Ø	0.29	0.14	0.10	0.16	0.19	0.21	0.13
			p	0.11	0.78	0.93	0.77	0.58	0.44	0.80
Allowing the police access to one's genetic information (Q4d)	r_s	-0.16	χ^2	5.63	4.15	3.69	8.77	9.11	3.00	1.14
	n	90	df	4	4	4	8	8	4	4
	p	.013	*p*	0.23	0.39	0.45	0.36	0.33	0.56	0.89
			V/Ø	0.25	0.21	0.20	0.22	0.22	0.19	0.11
			p	0.23	0.39	0.45	0.36	0.33	0.56	0.89
Attitudes' behavioural component (Q4)	r_s	-0.13	χ^2	16.09	23.91	**30.71**	21.66	31.63	17.85	**29.02**
	n	90	df	17	17	**17**	34	34	17	**17**
	p	0.24	*p*	0.52	0.12	**0.02**	0.95	0.58	0.40	**0.03**
			V/Ø	0.42	0.51	**0.58**	0.48	0.41	0.47	**0.56**
			p	0.52	0.12	**0.02**	0.95	0.58	0.40	**0.03**
Attitudes towards biotechnology (Q2, Q3, Q4)	r_s	-0.10	χ^2	49.26	44.66	45.20	46.68	86.60	47.90	44.58
	n	90	df	44	43	44	88	88	41	44
	p	0.33	*p*	0.27	0.40	0.42	1.00	0.52	0.21	0.45
			V/Ø	0.73	0.70	0.70	0.50	0.69	0.76	0.69
			p	0.27	0.40	0.42	1.00	0.52	0.21	0.45
Interest in biotechnology (Q5)	r_s	0.03	χ^2	0.02	4.67	1.47	2.66	3.54	0.75	1.26
	n	90	df	2	2	2	4	4	2	2
	p	0.81	*p*	0.99	0.10	0.48	0.62	0.47	0.69	0.53
			V/Ø	0.01	0.23	0.13	0.12	0.14	0.10	0.12
			p	0.99	0.10	0.48	0.62	0.47	0.69	0.53
Degree of information about biotechnology (Q6)	r_s	**-0.23**	χ^2	2.25	6.55	3.27	5.60	6.74	0.84	1.46
	n	**90**	df	3	3	3	6	6	3	3
	p	**0.03**	*p*	0.52	0.09	0.35	0.47	0.35	0.84	0.69
			V/Ø	0.16	0.27	0.19	0.17	0.19	0.10	0.13
			p	0.52	0.09	0.35	0.47	0.35	0.84	0.69
Importance of biotechnology education (Q9)	r_s	-0.06	χ^2	1.94	0.88	4.43	2.55	4.43	6.82	3.25
	n	90	df	3	3	3	6	6	3	3
	p	0.57	*p*	0.59	0.83	0.22	0.86	0.62	0.08	0.36
			V/Ø	0.14	0.10	0.22	0.12	0.16	0.29	0.19
			p	0.59	0.83	0.22	0.86	0.62	0.08	0.36

Age - seven ranks, 25-59 years old. Teaching experience - above/below 18 years. Experience teaching 12^{th} grade - Yes/No. Qualifications - BSc, MSc, PhD. Initial training background - Biology and/or Geology. Complementary training in biology/biotechnology - Yes/No. r_s - Spearman's rank correlation coefficient. *Ø* - Pearson's Phi. *V* - Cramér's V. df - degrees of freedom. Tests performed for a 95% confidence interval. Significant results are highlighted in bold.

Table IV.S2 (continued)

		Age		Gender	Teaching experience	Experience teaching 12^{th} grade biology	Qualifications	Initial training background	Complementary training in biology	Complementary training in biotechnology
School textbooks and other resources (Q10f, Q10g, Q10k, Q10o)	r_s	0.15	χ^2	5.54	8.58	7.14	33.64	20.80	11.06	14.49
	n	90	df	11	11	11	22	22	11	11
	p	0.17	*p*	0.90	0.66	0.79	0.05	0.53	0.44	0.21
			V/Ø	0.24	0.31	0.28	0.45	0.34	0.37	0.40
			p	0.90	0.66	0.79	0.05	0.53	0.44	0.21
Materials and infrastructures in schools (Q10m, Q10n)	r_s	**-0.24**	χ^2	3.98	4.26	7.56	9.88	10.82	5.42	4.58
	n	**90**	df	6	6	6	12	12	6	6
	p	**0.02**	*p*	0.68	0.64	0.27	0.63	0.54	0.49	0.60
			V/Ø	0.21	0.22	0.29	0.23	0.24	0.26	0.22
			p	0.68	0.64	0.27	0.63	0.54	0.49	0.60
Activity planning and development (Q10c, Q10d)	r_s	0.01	χ^2	3.98	9.87	5.33	6.22	16.71	8.61	9.02
	n	90	df	7	7	7	14	14	7	7
	p	0.93	*p*	0.78	0.20	0.62	0.96	0.27	0.28	0.25
			V/Ø	0.21	0.33	0.24	0.18	0.30	0.32	0.31
			p	0.78	0.20	0.62	0.96	0.27	0.28	0.25
12th grade biology curriculum and schedule (Q10i, Q10q)	r_s	-0.01	χ^2	6.91	13.39	14.21	21.05	**33.61**	6.97	8.36
	n	90	df	10	10	10	20	**20**	10	10
	p	0.91	*p*	0.73	0.20	0.16	0.39	**0.03**	0.72	0.59
			V/Ø	0.27	0.38	0.39	0.34	**0.43**	0.29	0.30
			p	0.73	0.20	0.16	0.39	**0.03**	0.73	0.59
Teacher's academic profile (Q10a)	r_s	0.02	χ^2	2.46	4.13	0.54	**16.36**	8.78	0.92	2.95
	n	90	df	4	4	4	**8**	8	4	4
	p	0.84	*p*	0.65	0.39	0.97	**0.04**	0.36	0.92	0.57
			V/Ø	0.16	0.21	0.08	**0.30**	0.22	0.11	0.18
			p	0.65	0.39	0.97	**0.04**	0.36	0.92	0.57
Availability of training (Q10e)	r_s	0.08	χ^2	2.33	2.74	0.74	5.63	14.39	2.40	0.49
	n	90	df	4	4	3	8	8	4	4
	p	0.49	*p*	0.68	0.60	0.86	0.69	0.07	0.66	0.97
			V/Ø	0.16	0.17	0.09	0.17	0.28	0.17	0.07
			p	0.68	0.60	0.86	0.69	0.07	0.66	0.97
Students' understanding (Q10h)	r_s	**0.23**	χ^2	3.60	6.72	4.50	7.10	8.69	8.44	9.00
	n	**90**	df	4	4	4	8	8	4	4
	p	**0.03**	*p*	0.46	0.15	0.34	0.53	0.37	0.08	0.06
			V/Ø	0.20	0.27	0.22	0.20	0.22	0.32	0.31
			p	0.46	0.15	0.34	0.53	0.37	0.08	0.06

Age - seven ranks, 25-59 years old. Teaching experience - above/below 18 years. Experience teaching 12^{th} grade - Yes/No. Qualifications - BSc, MSc, PhD. Initial training background - Biology and/or Geology. Complementary training in biology/biotechnology - Yes/No. r_s - Spearman's rank correlation coefficient. *Ø* - Pearson's Phi. *V* - Cramér's V. df - degrees of freedom. Tests performed for a 95% confidence interval. Significant results are highlighted in bold.

Table IV.S2 (continued)

		Age		Gender	Teaching experience	Experience teaching 12th grade biology	Qualifications	Initial training background	Complementary training in biology	Complementary training in biotechnology
Adequacy of materials for students (Q10p)	r_s	0.02	χ^2	1.63	4.41	5.99	**15.70**	7.16	5.57	1.67
	n	90	df	4	4	4	**8**	8	4	4
	p	0.82	p	0.80	0.35	0.20	**0.04**	0.52	0.23	0.80
			$V/Ø$	0.13	0.22	0.26	**0.29**	0.20	0.26	0.13
			p	0.80	0.35	0.20	**0.04**	0.52	0.23	0.80
Students' interest (Q10b)	r_s	-0.14	χ^2	**8.67**	0.99	2.42	5.53	2.66	1.07	2.79
	n	90	df	**3**	3	3	6	6	3	3
	p	0.18	p	**0.03**	0.80	0.49	0.48	0.85	0.78	0.43
			$V/Ø$	**0.31**	0.10	0.16	0.17	0.12	0.11	0.17
			p	**0.03**	0.80	0.49	0.48	0.85	0.78	0.43
Ethics in biotechnology education (Q10l)	r_s	**-0.21**	χ^2	2.42	2.03	0.99	3.51	1.80	1.34	1.17
	n	**90**	df	2	2	2	4	4	2	2
	p	**0.04**	p	0.30	0.36	0.61	0.48	0.77	0.51	0.56
			$V/Ø$	0.16	0.15	0.10	0.14	0.10	0.13	0.11
			p	0.30	0.36	0.61	0.48	0.77	0.51	0.56
Perceived limitations to biotechnology teaching (Q10)	r_s	-0.04	χ^2	20.56	16.59	26.70	42.59	**74.05**	28.24	21.24
	n	90	df	23	23	23	46	**46**	22	23
	p	0.68	p	0.61	0.83	0.27	0.62	**0.01**	0.17	0.57
			$V/Ø$	0.47	0.43	0.54	0.48	**0.63**	0.59	0.48
			p	0.61	0.83	0.27	0.62	**0.01**	0.17	0.57
Informal activities and collaborations (Q11a, Q11b, Q11c, Q11f)	r_s	-0.03	χ^2	10.44	10.07	14.00	26.71	31.98	10.57	12.28
	n	90	df	16	16	16	32	32	15	16
	p	0.98	p	0.84	0.86	0.60	0.73	0.47	0.78	0.73
			$V/Ø$	0.34	0.33	0.39	0.38	0.42	0.36	0.36
			p	0.84	0.86	0.60	0.73	0.47	0.78	0.73
Certified training (Q11d, Q11e)	r_s	0.17	χ^2	6.38	5.49	4.91	8.04	14.17	7.92	8.55
	n	90	df	7	7	7	14	14	6	7
	p	0.10	p	0.50	0.60	0.67	0.89	0.44	0.24	0.29
			$V/Ø$	0.26	0.25	0.23	0.21	0.28	0.31	0.31
			p	0.50	0.60	0.67	0.89	0.44	0.24	0.29
Practice improving behaviours (Q11)	r_s	0.09	χ^2	24.39	20.62	23.34	35.35	42.96	21.13	24.33
	n	90	df	22	22	22	44	44	21	22
	p	0.39	p	0.33	0.54	0.38	0.82	0.52	0.45	0.33
			$V/Ø$	0.51	0.48	0.50	0.44	0.48	0.51	0.51
			p	0.33	0.54	0.38	0.82	0.52	0.45	0.33

Age - seven ranks, 25-59 years old. Teaching experience - above/below 18 years. Experience teaching 12th grade - Yes/No. Qualifications - BSc, MSc, PhD. Initial training background - Biology and/or Geology. Complementary training in biology/biotechnology - Yes/No. r_s - Spearman's rank correlation coefficient. *Ø* - Pearson's Phi. *V* - Cramér's V. df - degrees of freedom. Tests performed for a 95% confidence interval. Significant results are highlighted in bold.

Table IV.S2 (continued)

		Age		Gender	Teaching experience	Experience teaching 12th grade biology	Qualifications	Initial training background	Complementary training in biology	Complementary training in biotechnology
Industrial and commercial information sources (Q8c, Q8d, Q8e)	r_s	-0.04	χ^2	**20.56**	11.17	13.19	20.03	19.95	12.22	15.62
	n	90	df	**10**	10	10	20	20	10	10
	p	0.68	*p*	**0.02**	0.34	0.21	0.46	0.46	0.27	0.11
			V/Ø	**0.47**	0.35	0.38	0.33	0.33	0.39	0.41
			p	**0.02**	0.34	0.21	0.46	0.46	0.27	0.11
NGOs and informal information sources (Q8a, Q8i, Q8j, Q8k Q8m)	r_s	0.06	χ^2	**23.99**	14.18	10.44	25.68	17.05	12.11	22.37
	n	90	df	**13**	13	13	26	26	13	13
	p	0.61	*p*	**0.03**	0.36	0.66	0.48	0.91	0.52	0.05
			V/Ø	**0.51**	0.40	0.34	0.37	0.30	0.38	0.49
			p	**0.03**	0.36	0.66	0.48	0.91	0.52	0.05
Scientific research and educational sources (Q8b, Q8g, Q8h)	r_s	-0.21	χ^2	7.57	8.12	6.32	**26.78**	10.32	3.28	3.10
	n	90	df	6	6	6	**12**	12	6	6
	p	0.05	*p*	0.27	0.23	0.39	**0.01**	0.59	0.77	0.89
			V/Ø	0.29	0.30	0.26	**0.38**	0.24	0.20	0.18
			p	0.27	0.23	0.39	**0.01**	0.59	0.77	0.80
Governmental and legislative sources (Q8f, Q8l, Q8n)	r_s	0.04	χ^2	13.42	12.31	14.42	10.83	15.52	15.08	7.59
	n	90	df	10	10	10	20	20	10	10
	p	0.71	*p*	0.20	0.27	0.16	0.95	0.75	0.13	0.67
			V/Ø	0.38	0.37	0.40	0.24	0.29	0.43	0.29
			p	0.20	0.27	0.16	0.95	0.75	0.13	0.67

Age - seven ranks, 25-59 years old. Teaching experience - above/below 18 years. Experience teaching 12th grade - Yes/No. Qualifications - BSc, MSc, PhD. Initial training background - Biology and/or Geology. Complementary training in biology/biotechnology - Yes/No. r_s - Spearman's rank correlation coefficient. *Ø* - Pearson's Phi. *V* - Cramér's V. df - degrees of freedom. Tests performed for a 95% confidence interval. Significant results are highlighted in bold.

CHAPTER V

Development of hands-on activities to promote biotechnology education

Subchapter 1

Natural antibiotics: a hands-on activity on garlic's antibiotic properties

Fonseca, M. J., & Tavares, F.
American Biology Teacher 2011
73(6), 342-346

Subchapter 2

The bactericidal effect of sunlight

Fonseca, M. J., & Tavares, F.
American Biology Teacher 2011
73(9), 548-552

Chapter V

Development of hands-on activities to promote biotechnology education

Subchapter 1

Natural antibiotics: a hands-on activity on garlic's antibiotic properties

Abstract

This work details a science experiment on garlic's antibiotic properties designed to acquaint high school and introductory-level undergraduate students with concepts such as natural antibiotics, bioactive substances, and biosafety. This activity is optimised to be implemented by teachers with limited experience in laboratory activities and/or in poorly equipped schools. A list of materials is provided, along with safety and procedural instructions, discussion topics, and assessment suggestions.

Garlic (*Allium sativum* L.) is widely used for its culinary and pharmacological properties, which include antimicrobial traits. Garlic extracts are known to inhibit the growth of fungi, protozoa, viruses, and numerous bacteria, namely *Salmonella* spp., *Staphylococcus aureus*, and *Escherichia coli* (Rahman, 2007). Garlic's antimicrobial activity is mainly ascribed to allicin, a bioactive compound present in injured garlic cloves (Harris, Cottrel, Plummer, & Lloyd, 2001). Allicin is considered a promising substitute or co-adjuvant for commercial antibiotics (Cutler & Wilson, 2004). In addition to their scientific interest, natural antibiotics like allicin can be used in classroom activities to introduce students to concepts like antibiotics and biosafety as well as basic microbiology techniques (Shimabukuro & Haberman, 2006). Furthermore, assessing bacterial susceptibility to natural antibiotics fosters the discussion of antibiotic resistance, a major public health issue worth addressing in school (Lawson, 2008). This work describes a hands-on activity on the antibiotic effect of garlic shoot juice (GSJ), an allicin-containing aqueous extract. *Bacillus cereus*, a rod-shaped, spore-forming, Gram-positive food-borne bacterium, is used to encourage students to investigate how aromatic herbs traditionally used in cooking can inhibit microbial flora. Its short generation time provides visual results in approximately one day, and its culturability can be preserved over long periods by freezing spore suspensions. This activity can be conducted in unequipped schools using inexpensive materials available in domestic kitchens.

Learning objectives

Students will:

- demonstrate the existence of phyto-antimicrobials;
- understand the concepts of antibiotics, antibiotic susceptibility, and biosafety;
- perform basic microbiology procedures;
- interpret and discuss experimental outcomes resulting from qualitative observations; and
- develop creativity skills related with motivation and imagination to devise alternative problem-solving strategies.

Materials

Bacillus cereus LMG 6923^{T} (strain for teaching purposes, BCCM^{TM}/LMG Bacteria Collection); fresh garlic bulbs; garlic press; 10 mL plastic syringe; gauze; 250 mL glass containers; glass rods;

gram scale; microwave oven; petri dishes; Pasteur pipettes and 1 mL pipettes; microbiological loops; agar (bacteriological or available in supermarkets and health food stores); meat (pork or beef); table sugar; kitchen salt; distilled water; 1 L growth-medium flasks (or equivalent microwave glass containers); glass burners; discard container with bleach (20%); ethanol (70%); paper towels; and Falcon and Eppendorf tubes (or equivalent).

Safety Concerns

This activity requires handling of bacteria. Therefore, students must act responsibly. They must wash their hands before and after the exercise, and they must not eat or drink in the lab. Work surfaces must be disinfected with ethanol (70%), and the materials used must be previously sterilised. Liquids, plastics and glassware can be sterilised using a microwave oven. Metallic materials can be sterilised using boiling water. All materials in contact with bacteria must be sterilised prior to disposal.

Methods

This activity is based on antibiotic susceptibility testing using the agar-diffusion method (Fig. V.1). Students should prepare the growth medium, the bacterial inoculum, and the GSJ extract. Bacterial susceptibility to GSJ on meat agar plates is assessed by observing inhibitory halos surrounding GSJ drops.

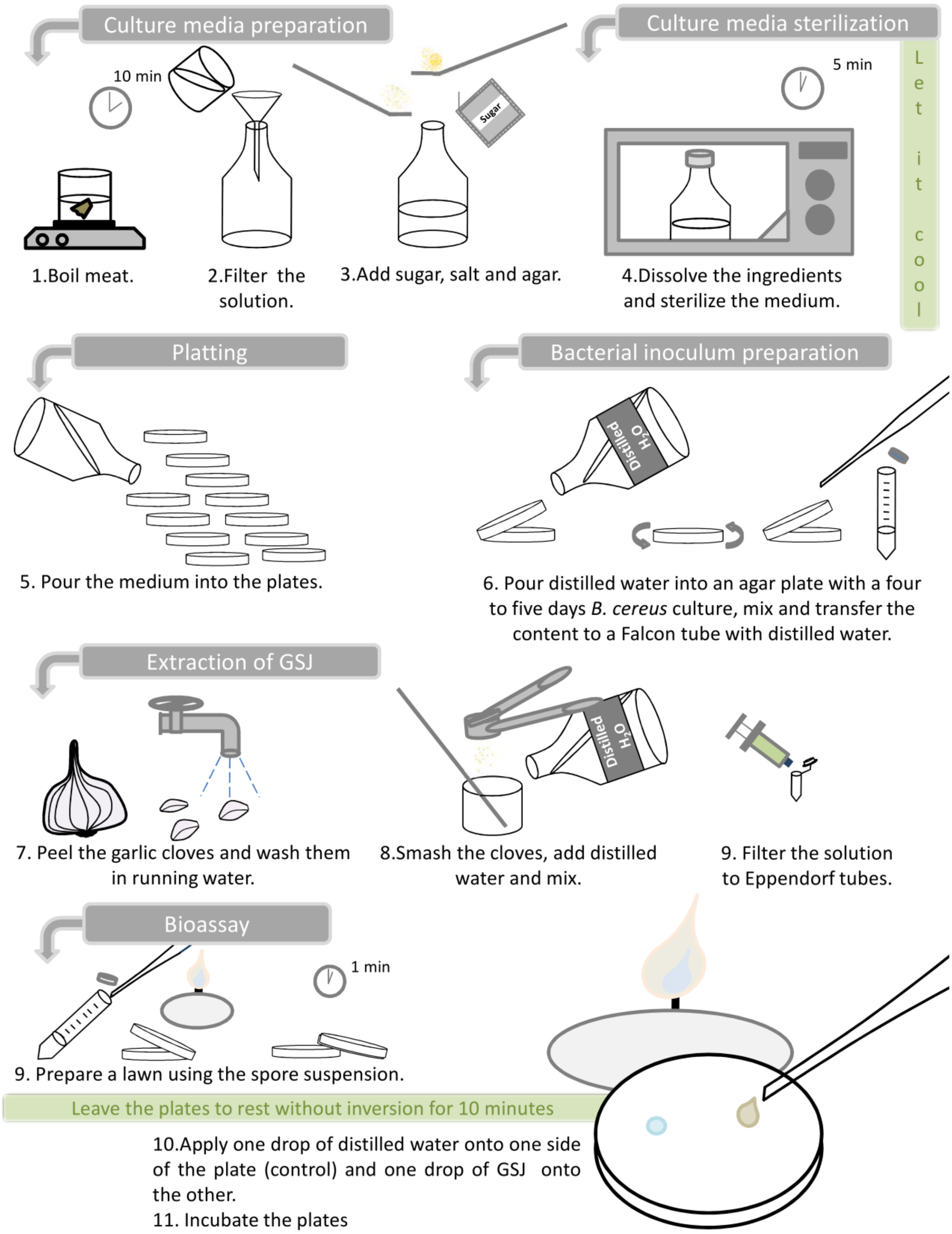


Fig. V.1. Schematic protocol for assessing antibiotic effect of garlic shoot juice (GSJ).

Growth media preparation

A meat agar medium replaces commonly used growth media such as nutrient agar. To prepare 250 mL of meat agar (enough for approximately 10 plates), boil 150 g of meat and filter the solution through gauze into a 1 L medium flask. Dissolve 6 g of sugar and 1.25 g of kitchen salt, and add 3.75 g of agar. Sterilise the medium using a microwave oven (900 W) for 5 minutes (or an autoclave for 15 minutes). To avoid spillage due to overheating, heat the medium in 1-minute increments interspersed with 15-second cooling periods. Because agar solidifies at ~42°C, pour it into the sterile Petri dishes (~25 mL per 9 cm-diameter dish) as soon as the medium temperature allows handling. Plating must be performed quickly in a recently disinfected bench. Allow the medium to solidify before using the plates.

Bacterial inoculum preparation

To prepare *B. cereus* spore suspensions, pour 5 mL of sterile distilled water onto a four- to five-day-old culture plate, suspend the spores with a sterile glass rod, and transfer the suspension to a sterile Falcon tube containing 20 mL of sterile distilled water. Dilute the suspension 10-fold (1:9 mL of sterile distilled water). Place the used pipettes in a container with bleach (20%). The suspensions can be stored in a freezer (–20°C) for at least 2 months.

GSJ extraction

Peel and wash three or four medium-sized garlic cloves with running water. Using a sterile garlic press, obtain ~5 g of smashed garlic, and then add sterile distilled water in the same proportion (1:1). Mix and filter the homogenate through a 10-mL sterile syringe containing sterile gauze into sterile Eppendorf tubes. The extracts can be stored at 4°C for at least 3 months.

Bioassay

Transfer 1 mL of spore suspension into each meat agar plate, and distribute it evenly by carefully tilting the closed plates. Position the plates at a slant for 1 minute, and then remove and discard the extra amount of suspension using a sterile pipette. Leave the plates to rest for 10 minutes to allow the bacterial cells to adhere to the medium. Using a Pasteur pipette, apply 1 drop of sterile distilled water (~20 µL) onto one side of each plate (control) and 1 drop of GSJ on the other. Leave the plates to rest for a few minutes, allowing the drops to diffuse into the medium, and then incubate the plates in an inverted position at room temperature for 24 hours (or at 37°C for ~12 hours).

Sterilise all biological waste in the microwave oven prior to disposal.

Results and Discussion

In this activity students witness the antibacterial effect of GSJ on *B. cereus* (Fig. V.2). Given garlic's pervasive culinary use, students are led to reflect on the health benefits of using it in food processing and preservation. This can lead them to engage in further investigations regarding, for example, the effects of different cooking techniques, times, and temperatures on garlic's antimicrobial activity. Because garlic is most commonly used in cooking, it was decided to prepare an aqueous extract. Students may be interested in testing other solvents used with garlic to cook or season foods, such as wine or vinegar.

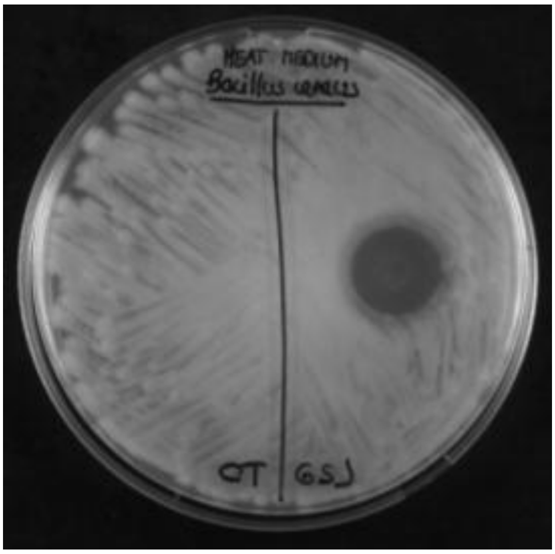


Fig. V.2. *Bacillus cereus* susceptibility to the antibiotic effect of GSJ (20 µL; 1:1) registered after incubation at room temperature for 24 hours.

Extensions and Discussion topics

Test the susceptibility of different bacteria to GSJ

Students can compare the inhibitory activity of GSJ on different bacteria by obtaining foodborne isolates from retail meat, for instance. They can distinguish different isolates on the basis of colony shape, size, texture, and colouring. So far, only bacteria naturally thriving on garlic are reported to resist allicin (Shim & Kyung, 1999). Searching for other resistant bacteria is a way to enhance students' motivation and creativity.

Explore how allicin is produced

Allicin is produced when raw garlic is injured and the vacuolar enzyme alliinase makes contact with allicin’s precursor in the cytoplasm, alliin (Harris et al., 2001; Rahman, 2007). A simple experiment assessing the effects of intact and sectioned garlic on bacterial growth demonstrates that allicin production requires cell damage (Fig. V.3). This experiment can lead to discussion of concepts related to enzymatic reactions, cell structure, and host defense mechanisms.

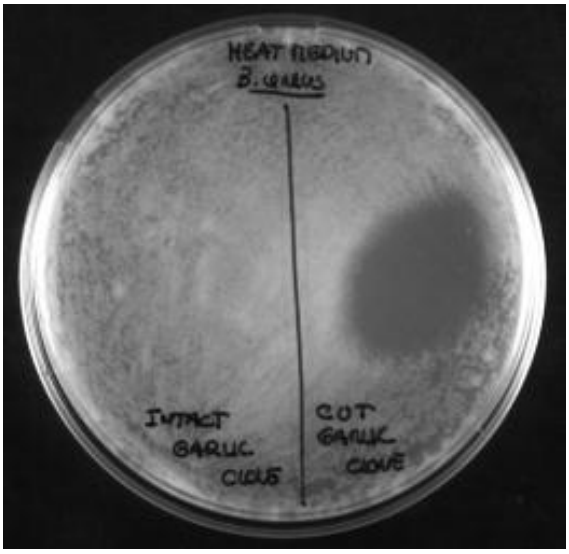


Fig. V.3. Demonstration of injury-induced allicin production.
Following inoculation with *B. cereus*, the plate was pressed with an intact (left) and a longitudinal section (right) of a garlic clove and incubated at 37^{0} C for 14 hours.

Screen different organisms for natural antibiotics

Most culinary herbs and spices are rich in antimicrobials, such as phenolic compounds (parsley, laurel), aldehydes (cinnamon, cumin), and acids (vanilla, rosemary) (Vigil, Palou, & Alzamora, 2005). By studying garlic’s antibacterial properties, students reflect on the concept of antibiotics and become aware of naturally occurring bioactive substances of pharmaceutical interest. This naturally sparks their curiosity, motivating them to propose experiments to screen different antibiotic-producing organisms.

Address plant defense mechanisms

Anti-phytopathogenic bioactive compounds, like allicin, participate in chemical plant defense mechanisms and have promising applications in phytoprotection programs (Slusarenko, Patel, & Portz, 2008). Exploring garlic's antibiotic properties introduces students to ecology concepts, such as predation and parasitism, and to physiology topics, including phytoanticipin, phytoalexin, and other secondary metabolites.

Curricular framing and Assessment

This activity is framed within the National Science Education Standards (NSES) for grades 9–12 (National Research Council [NRC], 1996), as summarised in Table V.1, and it can be adapted to instructional levels from high school through introductory undergraduate microbiology courses. The exercises presented promote students' abilities to conceptualise topics such as natural antibiotics and antibiotic resistance, to plan and execute experiments, and to develop inquiry-based scientific reasoning. The NSES (NRC, 1996) recommend that student assessments focus on microbiology and cell biology concepts, performance of laboratory techniques, and awareness about scientific inquiry. Accordingly, students may be asked to produce a report covering basic background information, the hypothesis tested, experimental design, results, discussion, and conclusions. In 10-minute sessions, they can present and discuss their reports and propose alternatives to overcome eventual drawbacks.

Conclusions

This activity addresses the concept of natural antibiotics by engaging students in a microbiological procedure used to assess antibiotic susceptibility. The exercises proposed promote students' critical, reflexive, and reasoning competencies. By using affordable and easily available materials, the experiment is accessible regardless of a school's laboratory facilities.

Table V.1.
Framing of the proposed experiments and discussion topics within the National Science Education Standards for grades 9 -12 (NRC, 1996).

Content Standards	Activity/Discussion Topic
Life Science Content Standard C	
The cell	Allicin synthesis Enzymatic reaction (concept of precursor, substrate, and enzyme) Cell structure (intracellular location of allicin's precursor and allinase enzyme)
The interdependence of organisms	Plant defense mechanisms (ecological concepts of parasitism and competition)
The behavior of organisms	Allicin synthesis Plant response to injury
Science & Technology Content Standard E	
Identify a problem or design an opportunity	Screen different organisms for natural antibiotics
	Test the susceptibility of different bacteria to garlic shoot juice
Science in Personal & Social Perspectives Content Standard F	
Personal and community health	Discussion of antibiotic resistance – natural antibiotics as substitutes or co-adjuvants of commercial antibiotics Test the susceptibility of different bacteria to garlic shoot juice
Population growth	Plant defense mechanisms (concepts of parasitism and competition)
Natural resources	Discussion of antibiotic resistance – antibiotics as natural resources

Acknowledgements

The authors are grateful to Catarina L. Santos for helpful comments and suggestions on the manuscript. MJF is supported by the FCT fellowship SFRH/BD/37389/2007.

References

Cutler, R. R., & Wilson, P. (2004). Antibacterial activity of a new, stable, aqueous extract of allicin against methicillin-resistant *Staphylococcus aureus*. *British Journal of Biomedical Science*, *61*(2), 71-74.

Harris, J. C., Cottrel, S. L., Plummer, S., & Lloyd, D. (2001). Antimicrobial properties of *Allium sativum* (garlic). *Applied Microbiology and Biotechnology*, *57*(3), 282-286.

Lawson, M. A. (2008). The antibiotic resistance problem revisited. *American Biology Teacher*, *70*(7), 405-410.

National Research Council. (1996). *National Science Education Standards*. Washington, D.C.: National Academy Press.

Rahman, M. S. (2007). Allicin and other functional active components in garlic: health benefits and bioavailability. *International Journal of Food Properties*, *10*(2), 245-268.

Shim, S. T., & Kyung, K. H. (1999). Natural microflora of pre-peeled garlic and their resistance to garlic antimicrobial activity. *Food Microbiology*, *16*(2), 165-172.

Shimabukuro, M. A., & Haberman, V. (2006). An aromatic adventure with allelopathy: using garlic to study allelopathy in the classroom. *American Biology Teacher*, *68*(4), 242-247.

Slusarenko, A. J., Patel, A., & Portz, D. (2008). Control of plant diseases by natural products: allicin from garlic as a case study. *European Journal of Plant Pathology*, *121*(3), 313-322.

Vigil, A. L. M., Palou, E., & Alzamora, S.M. (2005). Naturally occurring compounds – plant sources. In P. M. Davidson, J. N. Sofos, & A. L. Branen (Eds.), *Antimicrobials in Foods* (3rd ed.). (429-451). Boca Raton, FL: Taylor & Francis.

Subchapter 2

The bactericidal effect of sunlight

Abstract

Sunlight is required for vital biological processes. However, solar ultraviolet radiation can have a detrimental impact on living organisms, by acting as a natural mutagenic agent. With this activity, intended for middle school and high school, we propose a simple hands-on experiment to investigate the bactericidal effect of sunlight. The activity provides appealing visual results and opportunities for extension of inquiry. Procedural instructions, discussion topics, and assessment suggestions are detailed.

Sunlight is essential for vital biological processes, such as photosynthesis and vitamin D synthesis. However, solar ultraviolet (UV) radiation can be detrimental to living beings: it is associated with coral bleaching, sunburn, and melanoma. By interfering with DNA, proteins, and lipids, UV radiation can induce mutation, cell inactivation, growth reduction, and death (Pourzand & Tyrrell, 1999). Although cells possess UV-protection mechanisms, these do not fully prevent the genotoxicity of natural and artificial UV radiation. This raises obvious human-health concerns that are emphasised by the limited public awareness about the long-term consequences of UV radiation overexposure. The problem is particularly relevant among teenagers, who, in spite of numerous educational interventions, frequently reveal misinformed behaviours (Jones & Saraiya, 2006; Poorsattar & Hornung, 2007). An explanation for the narrow success of programs aimed at promoting safe sunbathing habits among high-school and college students may rely on the abstract notions required to understand the mutagenic effects of radiation, and on the need to shift from macro- to micro-levels of conceptualisation (Tibell & Rundgren, 2010). In this context, we present a simple and engaging practical experiment to investigate the lethal cellular effect of sunlight using bacteria as a model organism. Bacterial susceptibility to sunlight has long been demonstrated (Downes & Blunt, 1877), and UV-induced damage and repair in these organisms have been thoroughly studied (Goosen & Moolenaar, 2008). As fast-growing unicellular microorganisms, bacteria allow for clear visual evidence within a short period, which is likely to prompt students' curiosity and motivate them to deepen the understanding of the processes involved.

Learning objectives

In this activity, students expose bacteria to sunlight and witness its deleterious effect on cell survival. The students themselves prepare the growth medium and the plates and conduct the bioassay (Fig. V.4). In doing so, they

- demonstrate the lethal effect of sunlight on bacteria;
- discuss the impact of UV radiation on living cells;
- perform basic microbiology procedures; and
- interpret and discuss experimental outcomes resulting from qualitative observations.

Materials

- *Bacillus cereus* LMG 6923^{T} (strain for teaching purposes, BCCM^{TM}/LMG Bacteria Collection)
- Scale
- Autoclave
- Nutrient agar growth medium (available from Fisher Scientific, http://www.fishersci.com)
- Distilled water

- Ethanol (70%)
- Paper towels
- Discard container with bleach (20%)
- Glass burners
- Matches
- Thermometer
- 1-L growth-medium flasks
- Petri plates
- Falcon tubes
- Microbiological loops
- 1 mL pipettes
- Cellophane paper
- Cardboard paper
- Sunglass lenses (glass or plastic, with specified UV-protection features)

Safety concerns

This activity requires handling bacteria, and students must act responsibly throughout the experiment. Eating and drinking must not be authorised in the lab. Students must wash their hands before and after the experiment. Work benches must be disinfected with ethanol (70%), and the materials used must be previously sterilised. All biological waste must be sterilised prior to disposal using an autoclave (121°C, 15 minutes).

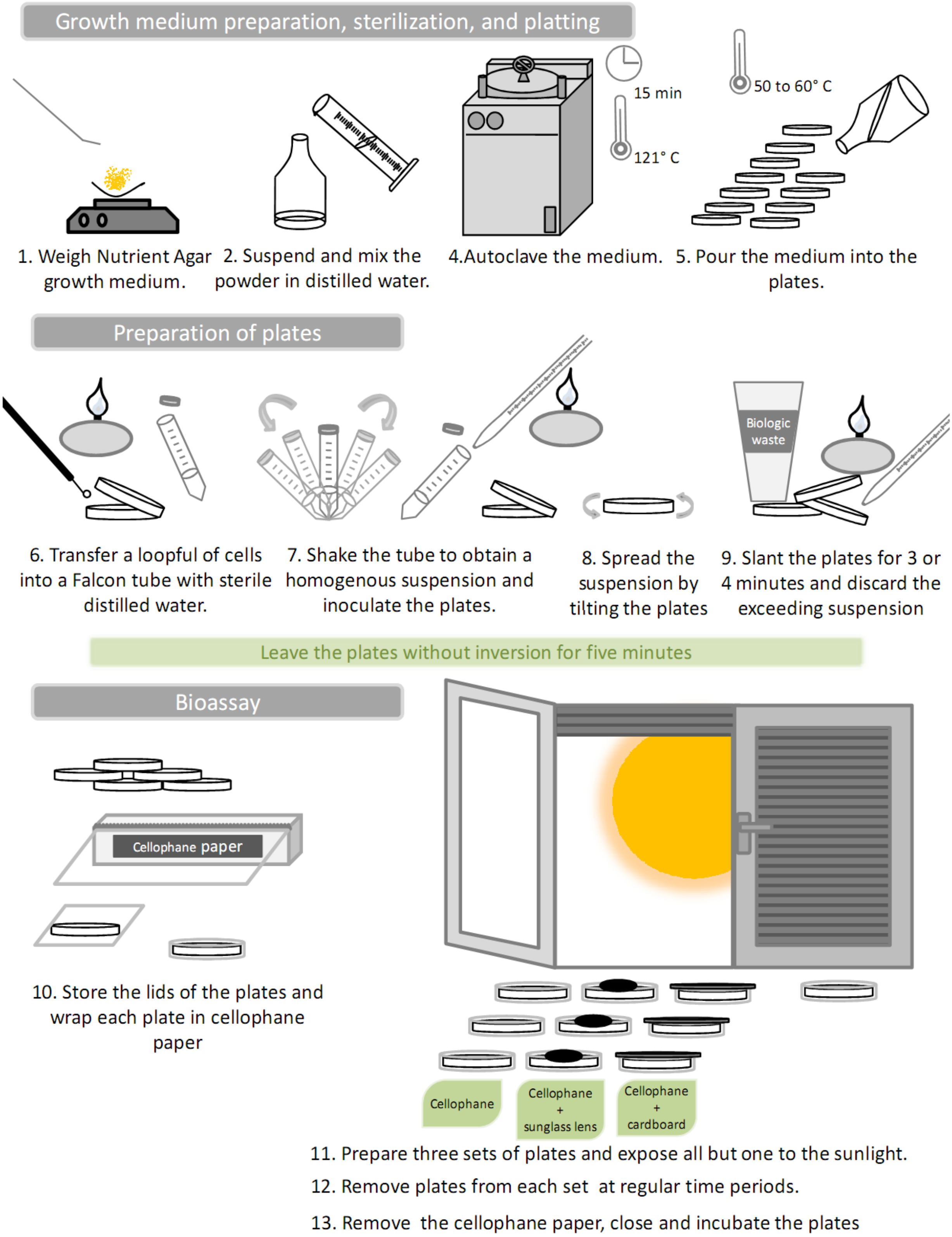


Fig. V.4. Mini-protocol for the assessment of sunlight's bactericidal effect.

Growth medium preparation

Prepare 250 mL of nutrient agar growth medium (enough for approximately ten 90 mm × 14 mm Petri plates), by dissolving 5.75 g of the powder in distilled water. Autoclave the medium at 121°C for 15 minutes. On a recently disinfected bench, as soon as the medium temperature allows handling (~50°C) pour it quickly into the plates (~25 mL per plate). Allow the medium to solidify and invert the plates. The plates can be used immediately or stored in the refrigerator for 2 to 3 weeks inside plastic sleeves to minimise dehydration. Alternative growth-medium-preparation and sterilisation instructions for use in schools with limited equipment and materials can be found in Fonseca & Tavares (2011).

Inoculation

Transfer a loopful of cells from a 24 hour *Bacillus cereus* culture into a sterile Falcon tube with 5 mL of sterile distilled water. Invert the tube vigorously to obtain a homogeneous suspension. Inoculate the plates with 1 mL of bacterial suspension. Spread the suspension evenly by carefully tilting the closed plates. Slant the plates for 2 or 3 minutes and remove the excess suspension using a sterile pipette. Place the pipettes in a discard container with bleach (20%). Leave the plates without inversion for ~5 minutes, allowing the cells to adhere to the medium.

Bioassay

Because glass and plastic filter some UV radiation, remove the lids from the inoculated plates. To avoid contamination, wrap each plate in cellophane paper and store the lids in the clean area. Keep one plate (control) and expose the inoculated surface of the other plates to sunlight, organised into three sets: (1) test-plates, wrapped in cellophane paper; (2) control-plates, with a sunglass lens on top of the cellophane; and (3) control plates, covered by cardboard. Remove and label one plate of each set every hour. Monitor the temperature every 30 minutes and, if there is a photometer available, the sunlight irradiance as well. Remove the cellophane paper and place the lids on the plates. Invert and incubate the plates at room-temperature for 48 hours (or at 37°C for 20 hours).

Results and Discussion

The results obtained demonstrate sunlight's lethal effect on *B. cereus* (Fig. V.5). There is an obvious decrease on the number of bacterial colonies, following the increase of sunlight exposure (Fig. V.5, A_1–A_3). The bacterial growth in the control plate that was not exposed to sunlight assures the viability of the bacterial inoculum (Fig. V.5, B). Mesophilic *B. cereus* strains grow optimally at 20–40°C. The growth in the control plates covered by cardboard demonstrates that the inhibition observed in the test plates was not temperature-induced (Figure 2, C). Finally, the growth pattern in the plates protected by sunglass lenses, acting as UV excluding filters, indicates that the deleterious effect of sunlight is mainly due to solar UV radiation (Fig. V.5, D). These results were obtained using a UV-A/UV-B protecting glass lens from a renowned brand. Lenses with different protection features are likely to produce variable results. This aspect is worth exploring, namely by discussing with the students the quality of the lens and its expected efficiency in protecting the human eye from solar UV radiation.

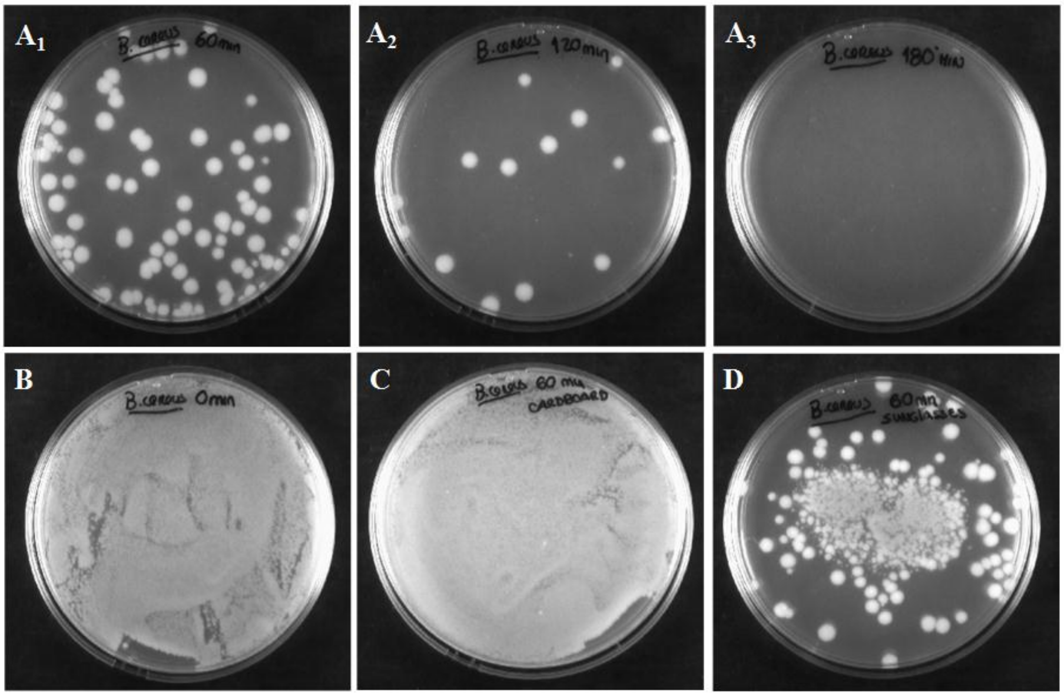


Fig. V.5. Demonstration of sunlight's lethal effect on *Bacillus cereus*.
Following inoculation, test plates were exposed to sunlight for one (A_1), two (A_2), and three ($_{A3}$) hours. Three controls were used: (B) no sunlight exposure, (C) cardboard protection, and (D) sunglass-lens protection. The results were obtained after incubation at room temperature for 48 hours. The bioassay was performed on 28 September 2010 (northern Portugal, 41°15'22.99''N, 8°63'89.14''W) from 12:45 to 15:45 hours (UV index = 5.1; ozone column = 296.4 DU; mean sunlight irradiance = 1186 μmol $m^{-2}s^{-1}$, range: 725–1200 μmol $m^{-2}s^{-1}$; mean temperature = 22.9°C, range: 20.5–26.7°C).

Extensions and Discussion topics

Address DNA damage and repair mechanisms

UV-induced mutagenic lesions are mainly ascribed to the dimerization of adjacent pyrimidine bases, leading to structural changes in the DNA molecule that interfere with replication and transcription processes. However, living organisms have developed protection and repair mechanisms to counteract the effects of solar UV radiation. These include the production of UV-absorbing pigments, like melanin, that act as physical barriers, and DNA repair systems, such as photoreactivation (photolyase enzyme) and excision repair (base and nucleotide excision repair). A detailed description of DNA repair mechanisms is available in Sinha & Häder

(2002). This activity can be used to introduce students in introductory undergraduate courses to concepts like mutation, mutagenic agents, and DNA repair mechanisms

Test different organisms for the effect of UV radiation

In this activity, *B. cereus*, a resistant spore-forming, Gram-positive bacterium, was used to illustrate the severity of sunlight's bactericidal effect. However, bacterial resistance to UV radiation varies. For instance, bacteria such as *B. subtilis* that produce photoprotective pigment-covered spores (Riesenman & Nicholson, 2000) are particularly resistant to solar UV radiation. Alternatively, yeast cells (*Saccharomyces cerevisiae*) can also be used. Testing the deleterious effect of sunlight with different organisms introduces students to ecological and evolutionary concepts such as biodiversity, adaptation, and natural selection.

Test different UV radiation wavelengths and UV screens

Ultraviolet-induced DNA damage is wavelength-dependent. Ultraviolet-A radiation (320–400 nm) causes only indirect damage through the production of reactive oxygen species, whereas UV-B (280–320 nm) and UV-C (100–280 nm) radiation also induce direct damage, because DNA strongly absorbs radiation at wavelengths below 320 nm (Fernández Zenoff, Siñeriz, & Farías, 2006). The most effective bactericidal effects occur from 200 to 280 nm (McDonnell, 2007), although DNA's absorption spectrum covers the UV-B wavelength. Students can test the effect of specific UV wavelengths on bacterial survival using different lamps. Since UV radiation is used in numerous applications, including forensics, phototherapy, and tanning beds, students may be motivated to discuss the human health effects of UV exposure. By exploring the protective efficacy of screens such as glass, plastics, photographic UV filters, or sunscreen-impregnated membranes, students are made aware of how personal decisions affect health.

Discuss the impact of atmospheric pollution

The anthropogenic release of atmospheric pollutants during the last decades has resulted in a noticeable depletion of the stratospheric ozone layer that typically shields Earth from UV-C and the majority of UV-B radiation (Rastogi, Richa, Sinha, Singh, & Häder, 2010). This has resulted in an increase of solar UV-B surface irradiance, which raises serious health concerns. The visualisation of sunlight's lethal effects on bacteria is an appealing way to engage students in the discussion of the environmental and personal health consequences of human interference in nature. Relevant information on atmospheric emissions is available from the Tropospheric Emission Monitoring Internet Service (http://www.temis.nl/index.php).

Curricular framing and Assessment

This activity addresses content standards in the NSES for grades 9 through 12 (NRC, 1996), as summarised in Table V.2. While engaging in the design and execution of experiments, students are introduced to microbiology, genetics, and ecology concepts; perform laboratory techniques; and develop scientific-reasoning skills. In small groups, students can manipulate one or more of the variables mentioned in the core and extension activities – for instance, exposure period, filter material, and model organism. They may be asked to convey their findings in an activity report, comprising the research question(s), methods, results, and main conclusions. A scoring rubric covering general procedural, methodological, and conceptual elements is provided in Table V.3. Students can also be assigned research exercises focusing on the discussion topics suggested. Ten-minute presentations can be organised, allowing students to share with their colleagues and reflect upon the outcomes of their investigations.

Table V.2

Contextualisation of the extension experiments and discussion topics in the National Science Education Standards for grades 9 -12 (NRC, 1996).

Life Science Content standard C
The cell
Address DNA damage and repair mechanisms Test different bacteria for the effect of UV radiation
Molecular basis of heredity
Address DNA damage and repair mechanisms Biological evolution Test different bacteria for the effect of UV radiation
Science and Technology Content standard E
Implement a proposed solution Evaluate the solution and its consequences
Test different UV radiation wavelengths and UV screens
Science in Personal and Social Perspectives Content standard F
Personal and community health
Address DNA damage and repair mechanisms Test different UV radiation wavelengths and UV screens Discuss the impact of atmospheric pollution
Environmental quality
Address DNA damage and repair mechanisms Discuss the impact of atmospheric pollution
Natural and human-induced hazards
Discuss the impact of atmospheric pollution

Conclusions

This simple and visually appealing hands-on activity fosters opportunities to familiarise middle school and high school students with abstract biology notions, such as mutation and mutagenic agent. Furthermore, it can be a persuasive strategy to promote increased awareness about the importance of adopting healthy sun-protection practices.

Table V.3
Scoring rubric for the evaluation of general procedural, methodological and conceptual elements.
The total score ranges from 0 to 24, according to the key presented.

	The student/group of students. . .		Score
Procedural Items	. . .registers observational data and results		1
	. . .prepares (or gives input about) the experimental setup		1
	. . .respects all biosafety instructions		1
	. . .successfully completes the activity		1
Methodological Items	. . .interprets and discusses the results obtained for. . .	. . .one set of plates	1
		. . .two sets of plates	2
		. . .three sets of plates	3
	. . .discusses the influence of variables, such as. . .		
	. . .length and time of the exposure period (considers the UV index, the ozone column, cloudiness. . .)		1
	. . .temperature effect		1
	. . .viability and concentration of the bacterial inoculum		1
	. . .type of filter used, namely:		
	Cellophane paper – What is the purpose of using it? Does it filter solar UV radiation?		1
	Cardboard – What information do the results obtained for the plates covered with cardboard give about the effect of temperature?		1
	Cardboard/sunglass lenses – Does cardboard filter the same types of radiation as sunglass lenses?		1
	Sunglass lenses – How is the protection capacity related to the quality of the lens?		1
	. . .addresses unexpected results. . .	. . .formulating new explanations and hypotheses	1
		. . .redefining the experimental setup	1
		. . .readjusting the variable control	1
	. . .understands the notion of model organism and is able to discuss the following questions:		
	Would the same results be obtained if different bacteria were used?		1
	How different would the results be if a multicellular organism were used instead of a unicellular one?		1
Conceptual Items	. . .formulates hypothesis about the effect of solar UV radiation on bacteria		1
	. . .predicts the bioassay results		1
	. . .is aware of positive and negative effects of sunlight		1
	. . .extrapolates the results obtained in light of a human health context:		
	understands the importance of healthy sun exposure habits, mentioning the need to avoid excessive exposure and to use adequate protection;		1
	understands that human activities resulting in the emission of atmospheric pollutants that damage the ozone layer can lead to increased solar UV surface irradiance.		1
		Total Score	**24**

Acknowledgements

The authors are grateful to Catarina L. Santos for helpful comments and suggestions on the manuscript. MJF is supported by the FCT fellowship SFRH/BD/37389/2007.

References

Downes, A., & Blunt, T.P. (1877). Researches on the effect of light upon *Bacteria* and other organisms. *Proceedings of the Royal Society of London*, *26*, 488-500.

Fernández Zenoff, V., Siñeriz, F., & Farías, M.E. (2006). Diverse responses to UV-B radiation and repair mechanisms of bacteria isolated from high-altitude aquatic environments. *Applied and Environmental Microbiology*, *72*(12), 7857-7863.

Fonseca, M. J., & Tavares, F. (2011). Natural antibiotics: a hands-on activity on garlic's antibiotic properties. *American Biology Teacher*, *73*(6), 342-346.

Goosen, N., & Moolenaar, G.F. (2008). Repair of UV damage in bacteria. *DNA Repair*, *7*(3), 353-379.

Jones, S. E., & Saraiya, M. (2006). Sunscreen use among US high school students, 1999–2003. *Journal of School Health*, *76*(4), 150-153.

McDonnell, G. E. (2007). *Antisepsis, Disinfection, and Sterilization: Types, Action, and Resistance*. Washington, D.C.: ASM Press.

National Research Council. (1996). *National Science Education Standards*. Washington, D.C.: National Academy Press.

Poorsattar, S. P., & Hornung, R.L. (2007). UV light abuse and high-risk tanning behavior among undergraduate college students. *Journal of the American Academy of Dermatology*, *56*(3), 375-379.

Pourzand, C., & Tyrrell, R.M. (1999). Apoptosis, the role of oxidative stress and the example of solar UV radiation. *Photochemistry and Photobiology*, *70*(4), 380-390.

Rastogi, R. P, Richa, Sinha, R.P., Singh, S.P. & Häder, D.-P. (2010). Photoprotective compounds from marine organisms. *Journal of Industrial Microbiology & Biotechnology*, *37*(6), 537-558.

Riesenman, P. J., & Nicholson, W.L. (2000). Role of the spore coat layers in *Bacillus subtilis* spore resistance to hydrogen peroxide, artificial UV-C, UV-B, and solar UV radiation. *Applied and Environmental Microbiology*, *66*(2), 620-626.

Sinha, R. P., & Häder, D.P. (2002). UV-induced DNA damage and repair: a review. *Photochemical and Photobiological Sciences*, *1*, 225-236.

Tibell, L. A. E., & Rundgren, C.-J. (2010). Educational challenges of molecular life science: characteristics and implications for education and research. *CBE Life Sciences Education*, *9*(1), 25-33.

CHAPTER VI

Validation of inquiry-based hands-on activities in informal and formal settings

Subchapter 1

Increasing awareness about antibiotic use and resistance: a hands-on project for high school students

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PLoS ONE, 7(9), e44699

Subchapter 2

Practical work in high school: assessing its effectiveness through an empirical-based analysis

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(submitted)

Chapter VI

Validation of inquiry-based hands-on activities in informal and formal settings

Subchapter 1

Increasing awareness about antibiotic use and resistance: a hands-on project for high school students

Abstract

Health-promoting education is essential to foster an informed society able to make decisions about socio-scientific issues based on scientifically sustained criteria. Antibiotic resistance is currently a major public health issue. Considering that irrational antibiotic use has been associated with the development and widespread of antibiotic resistant bacteria, educational interventions to promote prudent antibiotic consumption are required.

This study focuses on the outcomes of an interventional program implemented at the University of Porto, Portugal, to promote awareness about antibiotic resistance at high school levels (15-17 year old). The project Microbiology recipes: antibiotics à la carte articulates a set of wet and dry lab activities designed to promote the participants' understanding of concepts and processes underlying antibiotics' production and activity, such as the notion of mechanisms of action of antibiotics. Following a mix-method approach based on a pre-/post design, the effectiveness of this project was assessed by gathering data from surveys, direct observation and analysis of artifacts of 42 high school students (aged 15 and 16 years).

The results indicate that the participants developed a more comprehensive picture of antibiotic resistance. The project was shown to promote more sophisticated conceptualisations of bacteria and antibiotics, increased awareness about the perils of antibiotic resistance, and enhanced consciousness towards measures that can be undertaken to mitigate the problem. The participants regarded their experiences as enjoyable and useful,

and believed that the project contributed to improve their understanding and raise their interest about the issues discussed. Furthermore, there were also improvements in their procedural skills concerning the laboratory techniques performed.

This study evidences the possibility of increasing high school students' awareness about the consequences of antibiotic resistance and the importance of judicious antibiotic use. The findings inform about the educational benefits of incorporating hands-on activities in science education programs.

Introduction

The development of antibiotic drugs provided the basis for infectious disease control. However, with the emergence and widespread of drug-resistant and multidrug resistant bacteria, antibiotic resistance has become a major public health issue. Paradoxically, the overuse and misuse of antibiotic drugs have scaffolded this turn of events in the warfare against bacterial infectious disease (Orzech & Nichter, 2008; van de Sande-Bruinsma et al., 2008). Unreasonable antibiotic consumption in human healthcare and farm animal husbandry increases the selective pressure for resistant bacteria, accelerating the rhythm at which resistance spreads. In this context, as emphasised by the World Health Organization, in the report "Overcoming antimicrobial resistance" (World Health Organization, 2000) and 11 years later by selecting the theme "Combat Drug Resistance" for World Health Day 2011, it is necessary to promote informed decision-making about antibiotic consumption. Accordingly, the calls for public health education programs have resulted in numerous educational resources, such as the ones made available by the Centers for Disease Control and Prevention (http://www.cdc.gov/drugresistance/campaigns.html) and the Alliance Working for Antibiotic Resistance Education (http://www.aware.md/). Nevertheless, reliable indicators of the efficacy of most of these resources are still missing (Sabuncu et al., 2009). Furthermore, studies show that the general public remains unaware of basic aspects related with antibiotics' modes of action, and frequently engage in misinformed behaviours (Grigoryan et al., 2007; McNulty et al., 2007a). This reinforces the importance of developing health education programs to promote appropriate antibiotic use and enhance public understanding about antibiotic drugs.

Considering that educational programs targeting young people expectably contribute to a future generation of scientifically literate antibiotic users, the purpose of this study was to develop, implement and assess a hands-on interventional program to promote awareness about antibiotic resistance at high school levels (ages 15-17 years). The main goal of the project Microbiology recipes: antibiotics à la carte was to promote the participants' understanding of biological concepts and processes underpinning the notion of antibiotic production and activity, by eliciting their engagement in microbiology procedures.

Microbiology recipes: antibiotics à la carte

This study focuses on the outcomes of the project Microbiology recipes: antibiotics à la carte, implemented in the scope of Porto's Junior University (UJr) (http://universidadejunior.up.pt/index.php/paginas/english/home). As a member of the European Children's University Network (EUCU.NET, https://sites.google.com/site/eucunetevents/), UJr is a summer school-based initiative that seeks to promote Science & Technology, Arts, Humanities and Sports education amongst elementary and high school students (aged 11 to 17). Each year, a list of projects designed by university lecturers and implemented by undergraduate and graduate students within the university facilities is made available in UJr's website, so that interested students can chose and apply to the one(s) they prefer.

Microbiology Recipes: antibiotics à la carte was developed as a one-week long inquiry-based hands-on project for high school students. Whereas traditional educational interventions to decrease antibiotic use and improve knowledge about antibiotics have mainly relied on information campaigns and state or nationwide programs (Belongia et al., 2005; Cebotarenco & Bush, 2008; Finkelstein et al., 2008; Huttner et al., 2010; Mölstad et al., 2008; Sabuncu et al., 2009), practical activities in this scope are much scarcer (Krist & Showsh, 2007; Lecky et al., 2010; Longtin, Guilfoile, & Asper, 2004; Wassmer, Kipe-Nolt, & Chayko, 2006). Practical work, generally understood as activities that demand an active engagement in the manipulation of objects and materials (Abrahams, 2011; Abrahams & Millar, 2009; Toplis, 2011), has been known to scaffold students' learning by: sparking their interest (Abrahams &

Millar, 2009; Rudduck & McIntyre, 2007); fostering social interaction (Rudduck & McIntyre, 2007; Toplis, 2011); and promoting scientific reasoning by allowing to make connections between observable phenomena and the underlying ideas (Abrahams, 2011; Rudduck & McIntyre, 2007; Wellington, 2005). Practical work can be an efficient strategy to promote students' knowledge about antibiotics and antibiotic resistance, considering that at high school levels, the understanding about these concepts can be compromised by: their abstract nature; misconceptions about the notion of microorganism (Jones & Rua, 2008; Milandri, 2004); and difficulties in transitioning between micro and macro levels of conceptualisation (Tibell & Rundgren, 2010).

To meet these concerns, the project's instructional design was purposely built upon a practical component, following the adaptation and extension of a practical activity on the antibiotic effect of natural phytoactive compounds (Fonseca & Tavares, 2011).

The project began by an introductory session in which its scope and aims, the activities to perform, and basic laboratory safety rules were presented to the participants. Following this introduction, as outlined in Fig. VI.1, the participants took part in integrated activities, aligned with the goals of the project and with the contents addressed: three interactive lectures, six wet lab activities, and two dry lab activities.

The contextualisation of the project was made during an interactive lecture covering scientific notions and concepts related to bacteria, antibiotics and antibiotic resistance that have been discussed as pivotal in previous research studies (Brookes-Howell et al., 2011; Davey, Pagliari, & Hayes, 2002; Milandri, 2004; Simonneaux, 2000), including: bacteria's growth, adaptability, and ubiquity; antibiotics' activity spectrum, modes of action, and production processes; and the causes and consequences of bacterial resistance to antibiotics (Fig. VI.1).

Two additional lectures were used to introduce two practical activities. One of these - Meet *Bacillus cereus* provided the theoretical background for a wet lab activity on bacterial growth and diversity (Fig, VI.1), in which the participants made and observed slide preparations of bacterial cells at different growth stages.

The other interactive lecture introduced a bioinformatics exercise addressing the evolution of a gene coding for resistance to an antibiotic (*Supporting information - Fig. VI.S1-B*). The purpose was to acquaint the participants with tools commonly used in research with which they were not familiar. Most importantly, it was intended to reinforce the significance of antibiotic resistance, by providing an evolutionary perspective.

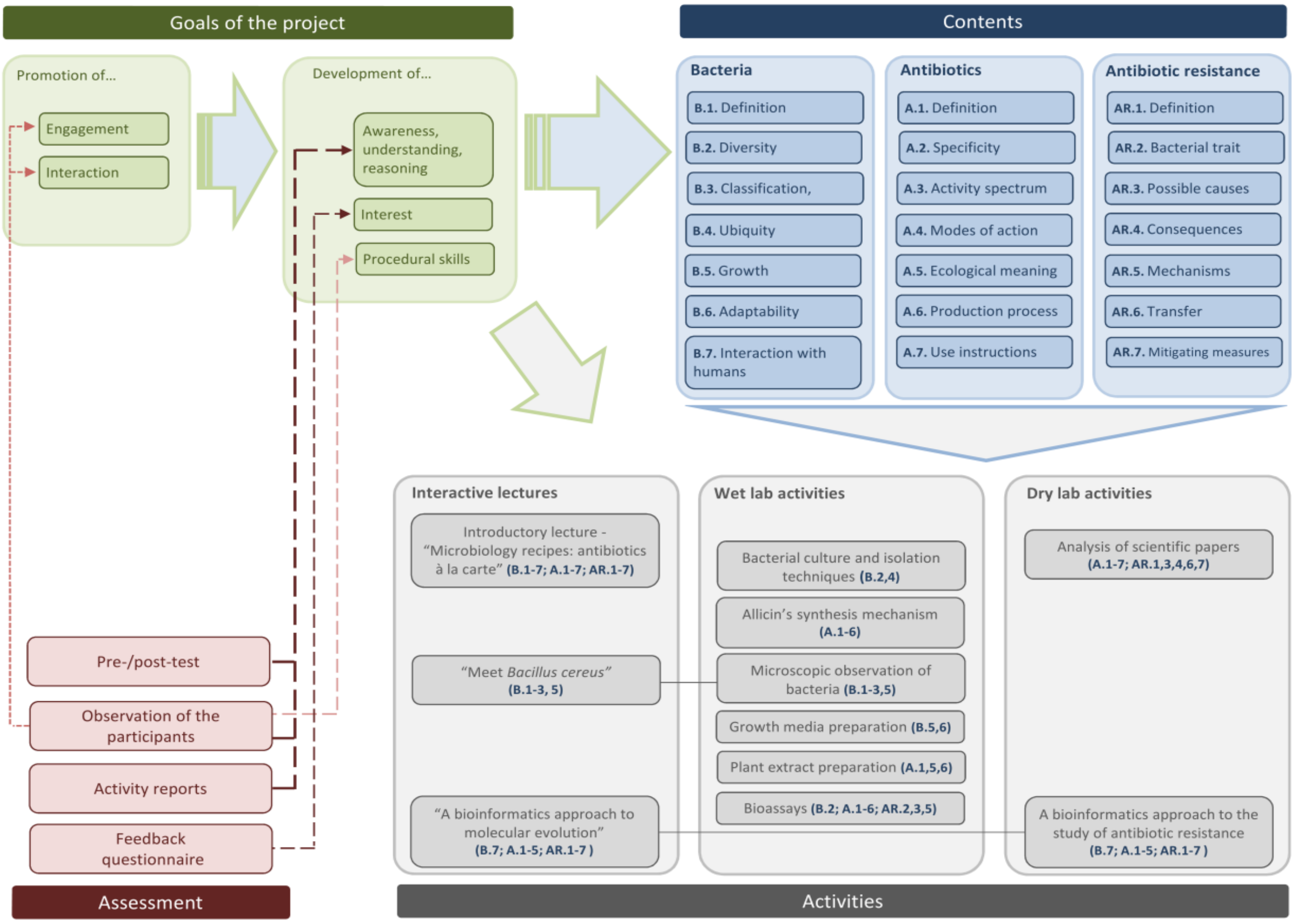


Fig. VI.1. An holistic perspective of the project's rationale and implementation.
The goals of the project, the contents covered, the activities carried out, and the assessment instruments used in the study were purposely articulated to provide a comprehensive depiction of its educational effectiveness.

The other dry lab activity involved the analysis of scientific papers, carried out with the main objective of illustrating how research findings are reported within the research community, and discussing published scientific evidence about the widespread of antibiotic resistance, antibiotic use behaviours, and natural compounds as alternatives or coadjuvants of commercial antibiotics.

In one of the remaining five wet lab activities, the participants practiced bacterial culture and isolation techniques, by collecting and growing environmental samples from various sources, including door knobs, keyboards, cellphones, foodstuffs, plant leafs, and their hands and nostrils. The main goal was to witness the diversity and ubiquity of bacteria.

In another session, the participants discussed the biosynthesis process of allicin, the major phytoactive compound to which garlic's antibiotic properties are ascribed, while carrying out a practical activity that demonstrates that garlic's antibiotic compounds are induced upon injury (*Supporting information - Fig. VI.S1-A*). They were introduced to several measures required to handle such volatile, unstable substances and reflect about the ecological meaning of the production of compounds with antibiotic properties, especially amongst bacteria.

The participants were also engaged in the preparation of growth media. Besides the development of procedural skills, this was expected to foster the acknowledgement that bacteria have specific requirements that determine their growth.

Another activity involved the preparation of plant extracts from organisms described in the literature as having antibiotic properties, some of which were brought to the laboratory by the participants. The tasks performed were expected to give an idea of the complexity involved in screening and testing natural antibiotics.

Using the agar diffusion method, bioassays were performed with the extracts previously prepared and with commercial antibiotics, to allow a comparative overview. The participants observed, registered and discussed the results obtained, and prepared a brief activity report, which was discussed, aiming to summarise the key points of the contents addressed and the procedures carried out throughout the project.

A comprehensive overview of the project's rationale, including the contents addressed, is available in Fig. VI.1, and the schedule and distribution of the activities throughout the week is presented in *Supporting information - Fig. VI.S2*.

To evaluate the effectiveness of Microbiology recipes: antibiotics à la carte, an assessment strategy combining qualitative and quantitative approaches was set up (Fig. VI.1). The main research question driving this investigation was: are there significant changes in high school students’ awareness and understanding about antibiotic use and resistance as the result of their participation in this hands-on project? The study also sought to determine the impact of the project on the participants’ interest about the topics addressed and their procedural competencies. Among the findings obtained, it was noticed that the project impacted positively on the participants’ awareness and understanding about bacteria, antibiotics, and antibiotic resistance. The innovative nature of the project, concerning the implementation setting and the combination of activities ranging from bioinformatics to natural antibiotic testing, contributed to dismiss misconceptions, enhance the sense of self-responsibility, and promote the development of procedural skills.

Methods

Participants

The study involved 42 high school science students who participated in the project in 2010 (*n*=25) and 2011 (*n*=17). The participants (30 females, 12 males, aged 15 and 16 years) had just finished grades 10 (*n*=28) and 11 (*n*=14). All of them enrolled in the project by their own initiative, by registering online at UJr's website, and following the procedures required. As most of UJr's applicants are underage, the parents' consent is formalised through the payment of a registration fee. Taking into account all ethical requirements, each project is institutionally approved by both UJr's organising committee and the board of direction of each Faculty where the activities take place. For the purpose of this study, the assessment of the project's outcomes was depicted in the project's planning, together with the outline of every activity proposed. Upon entering the project, the participants were invited to take part in the study and informed of its nature and aims. They were given the chance to participate in the project without participating in the study, and to withdraw from the latter should they wish to. All the data collected were processed and analysed anonymously.

According to the Portuguese biology curricula, the 10th and 11th grade biology and geology programs include contents related, respectively with cell structure and uni-/multicellularity (DGIDC, 2001), taxonomy and classification systems (DGIDC,2003). However, the concept of antibiotics is only addressed at 12th grade biology (DGIDC, 2004). Therefore, in spite of being science students, these participants were not expected to be particularly knowledgeable about antibiotic resistance as a result of their formal education.

Data collection

To obtain a broader, more inclusive depiction of the effectiveness of the project, a mixed methods approach was used (Cohen, Manion & Morrison, 2011) combining questionnaire analysis, observations, and analysis of activity reports (Fig. VI.1). Qualitative and quantitative data were gathered on the participants' understanding, reasoning, interest and procedural skills. Considering the reported influence that students' engagement and interaction with their peers has on learning (Packer & Ballantyne, 2004; Rudduck & McIntyre, 2007; Schunk & Mullen, 2012; Toplis, 2011), these two aspects were also evaluated.

To assess the participants' understanding and reasoning about bacteria, antibiotics and antibiotic resistance, an open-ended pre-/post-test was developed (Table VI.1), considering topics available in previous studies (Buke et al., 2005; Davey et al., 2002; Grigoryan et al., 2007; McNulty et al., 2007a,b). Common misconceptions such as antibiotic use for flu treatment (Buke et al., 2005; Davey et al., 2002; Grigoryan et al., 2007), or the notion that resistance refers to a characteristic of the host organism (Brookes-Howell et al., 2011) were considered.

Naturalistic observations (Goodwin, 2009) were carried out to identify misconceptions and reasoning difficulties, and to evaluate the participants' interaction and engagement. The participants prepared activity reports, which were also examined, with the main purpose of assessing how they interpreted, explained and discussed their findings.

Finally, a self-reported questionnaire with closed and semi-open questions was used to gather the participants' feedback about their experience in the project (Table VI.2). Based on previous studies on students' views about effective practical work lessons (Rudduck & McIntyre, 2007; Toplis, 2011), particular attention was given to the interest, difficulty, usefulness and meaningfulness of the activities.

Table VI.1
Pre-/post-test used to assess the participants' understanding and beliefs about bacteria, antibiotics and antibiotic resistance.

Q1. How do you define bacteria?
Q2. Are bacteria beneficial or harmful for humans? Give some illustrative examples.
Q3. Describe the main phases in bacteria's growth cycle.
Q4. Do you think that bacterial infectious diseases are currently under control? Justify your answer.
Q5. How do you define antibiotics?
Q6. How do you explain the selectivity of antibiotics for microorganisms?
Q7. Imagine that you have the flu, you are feverish and aching. In this situation, do you think that antibiotic prescription would be a suitable solution? Justify your answer.
Q8. Describe how an antibiotic is produced.
Q9. How do you define antibiotic resistance?
Q10. List measures that can be used to avoid or reduce antibiotic resistance.
Q11. Do you agree with the statement: *The progeny of antibiotic resistant bacteria is also resistant*. Justify your answer.

Table VI.2
Feedback questionnaire.

Rate the following aspects on a scale from 1 (Very low/Not at all…) to 5 (Very high/Completely…)	
• Organisation and structuring of the contents	• Effort required
• Difficulty of the contents	• Contribution to understand the issues discussed
• Interest of the contents	• Contribution to critically reflect about the issues discussed
• Difficulty of the techniques	• Contribution to enhance the curiosity about the issues discussed
• Articulation between content and techniques	• Overall satisfaction about the project
• Suitability of materials used	
List the…	
… most positive aspects (open question)	... less positive aspects (open question)
Make the comments and suggestions you find necessary (open question)	
Evaluate the project in a scale of 1 (Mediocre) to 5 (Excellent)	

Data analyses

Questionnaire data were recorded, codified and categorised. The content analysis of the participants' responses to the open questions was performed following the recommendations available in Krippendorff (2004) and Weber (1990).

The analyses of the participants' pre- and post-test responses were conducted with the purpose of measuring the range of impact of the project, and unveiling the qualitative variations in the participants' reasoning. Besides determining the number of students who provided correct and incorrect responses, the content of those responses was scrutinised. For every response, the number of correct and incorrect notions was quantified, and their pre-/post-test variation measured. To gauge changes in the participants' reasoning, coding rubrics were developed for each question (*Supporting information - Table VI.S1*), informed by Bloom's taxonomy of cognitive domains, a classification system that categorises cognitive thinking skills according to levels of abstraction (Lord & Baviskar, 2007; Moore & Stanley, 2009; Weil & Kincheloe, 2004). The interpretation of the participants' responses was based on previously defined guidelines (Crowe, Dirks, & Wenderoth, 2008; Lord & Baviskar, 2007).

Using IBM SPSS Statistics 20, descriptive and inferential statistical analyses were performed to examine and compare the responses obtained. One sample *t*-tests were used to examine the mean scores for the items measured on five point Likert-type scales. Scores below, equal or above the midpoint of the scale (test value=3), were respectively considered indicative of negative, neutral or positive responses, for a 95% confidence interval. For the open-ended questions, paired samples *t*-tests were used to compare the pre-/post-test variation in the number of correct/incorrect notions provided per response, and in the rubric scores. Variations were considered significant for $p<0.05$. The strength of the mean differences registered was measured using Cohen's *d* (Cohen, 1988). Effect sizes equal to 0.2, ranging from 0.5 to 0.8, or above 0.8, were respectively considered small, medium or large (Cohen, 1988; Gravetter & Forzano, 2009). For the responses codified as dichotomous variables (e.g. a "Don't know" answer), the McNemar test was used to compare pre-test and post-test scores (Hill & Lewicki , 2006).

Results

Pre- and post-test performance

The data collected point towards the improvement of the participants' understanding of the concepts of bacteria, antibiotics and antibiotic resistance, and of their awareness about bacterial infectious disease control, antibiotic use and bacterial resistance to antibiotics.

Significant pre-/post-test differences were observed for every question in the questionnaire ($p<0.05$). There were significant improvements in the quality of the participants' responses, as demonstrated by the enhancement in the rubric scores for the eleven questions presented (*Supporting information - Table VI.S2*; see *Supporting information - Table VI.S1* for details on the pre-/post-test scoring rubrics). For most questions, there was an increase in the number of students able to achieve top-level responses in the post-test (Q1: 1 vs. 11; Q3: 0 vs. 13; Q4: 0 vs. 5; Q5: 0 vs. 6; Q7: 1 vs. 16; Q9: 12 vs. 23; Q10: 0 vs. 3). This improvement can be ascribed to:

- the increase in the amount of correct notions or valid claims provided per response for every question presented (See *Supporting information - Table VI.S2*);

- the decrease in the amount of incorrect notions or invalid claims provided per response for questions Q1, Q4, Q5, Q7, and Q9 (See *Supporting information - Table VI.S2*).

There was also an increase in the number of participants conveying correct notions in questions Q1, Q2, Q3, Q5, Q6, Q8, Q9, Q10 and Q11 (See *Supporting information – Table VI.S3*), and a decrease in the number of participants who did not answer questions Q3 (27 vs. 0, $\chi^2(1)=23.04$, $p<0.001$), Q6 (20 vs. 5, $\chi^2(1)=11.53$, $p<0.001$), Q8 (33 vs. 9, $\chi^2(1)=22.04$, $p<0.001$), Q10 (11 vs. 0, $\chi^2(1)=9.09$, $p<0.001$), and Q11 (19 vs. 3, $\chi^2(1)=14.06$, $p<0.001$).

Regarding question Q7, the participants' opinion changed from considering that antibiotics are a suitable solution to treat flu, to the perception that this is not reasonable (See *Supporting information - Table VI.S3*). In what concerns question Q4, whereas in the pre-test there were more participants who thought that bacterial infectious diseases are contained, by the end of the project most of them were aware that these represent a major public health issue (See *Supporting information - Table VI.S3*).

Observation of the participants

Misconceptions and difficulties. No relevant difficulties or misconceptions were identified during the activities, although several participants admitted that they "did not know the human body harbours so many bacteria" and that antibiotic drugs affect bacteria from the human microbiota. Also, whilst most of them knew that edible plants and herbs may produce substances with pharmacological interest, they did not know that plant extracts can be used to inhibit bacteria.

Procedural competencies. Most of the participants mentioned that they were unfamiliar with the laboratory procedures carried out and frequently asked questions about the surrounding laboratory equipment, wondering if it was "similar to the equipment available in research labs". From the start, all of them were very careful in handling the materials and performing every procedure. Nevertheless, in addition to an evident enhancement in their self-confidence, their procedural competencies improved considerably along the week, as illustrated in Fig. VI.2. This was also observed for their engagement in the dry-lab activities. Although most of them had never experienced working with bioinformatics tools, they had no problems in following the protocols and discussing the issues raised.

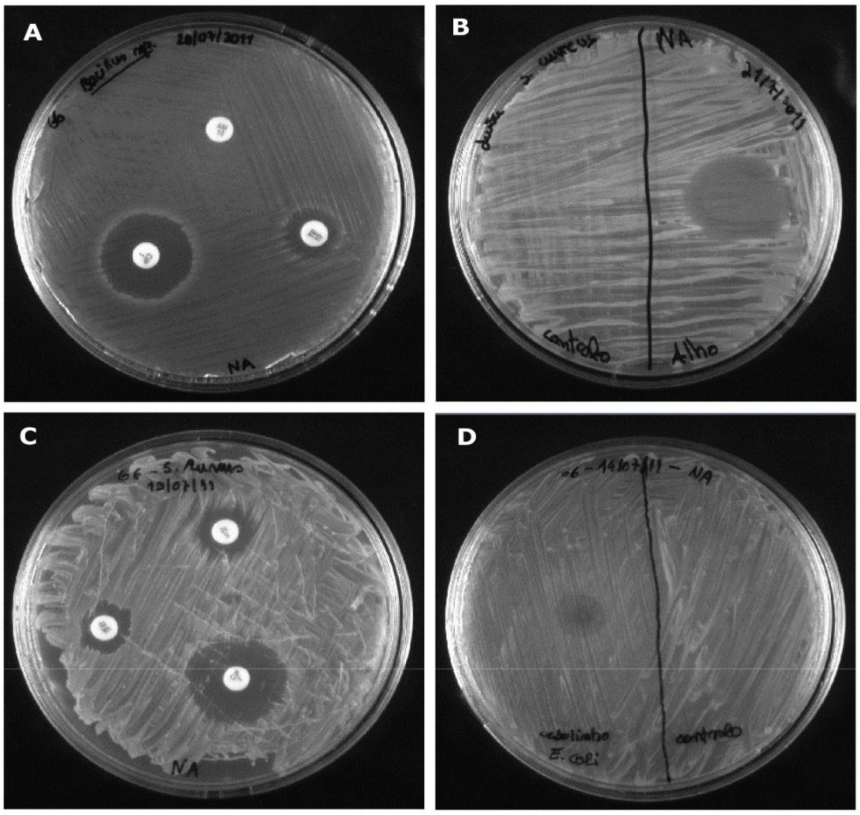


Fig. VI.2. Positive results evidencing the procedural competencies of the participants.
A – antibiograms obtained with commercial antibiotics – the even growth of the bacterial culture indicates an efficient inoculation; the clear inhibitory halos surrounding two antibiotic disks indicate that these were placed carefully onto the plates. B – Although the bacterial culture is not as evenly distributed as in 'A', its density allows the visualisation of a halo in the point where a drop of garlic aqueous extract was applied (left side); the fact that the inhibitory halo is cantered in relation to the half of the plate in which it was applied suggests the cautiousness of the participant who prepared the plate. Plates C and D were prepared by the same group of participants in consecutive days. The results evidence an improvement of their streaking technique. In C, an excess of inoculum appears to have been irregularly and incompletely distributed. The scratches in the medium (from the left to the middle of the plate) are suggestive of excessive pressure while streaking. In contrast, in D the inoculum is much more evenly distributed.

Engagement and interaction. In spite of the expectable side talk, the participants were actively engaged in every task that they were asked to perform at a seemingly steady level throughout the week. They were eager to share their experiences as antibiotic consumers with their colleagues, and were particularly interested in how antibiotics are produced and act. They repeatedly mentioned that they were "going to share this information with relatives and friends", because people "need to be alerted about this".

The participants were quite excited about testing natural antibiotic compounds, and having the chance to get acquainted with new techniques and equipment. Most of them were not acquainted with their colleagues, but by the second day all of them were working harmoniously. Everyone was called out by their names and cooperated with one another. The environment was light and easy-going, although there was some healthy competition between groups.

Participants' activity reports

While varying in structure and degree of detail, the participants' reports included a description of the activities conducted and a summary of the main learning outcomes. No major errors or misconceptions were detected, although there was some confusion regarding the distinctiveness between horizontal and vertical gene transfer.

There were specific references to the fact that "resistance [genes] can be transmitted between bacteria", and that "it is important to be careful about how antibiotics are used". Some participants mentioned the social interaction that took place, stating that "the environment helped [them] to feel at ease" while engaging in the activities.

Participants' feedback on the project

The participants reported that they enjoyed participating in the project ($p<0.001$) and that it contributed to enhance their curiosity about the subjects addressed ($p<0.001$). They though that the contents were interesting ($p<0.001$), well-structured ($p<0.001$), and adequately articulated with the techniques ($p<0.001$). They believed that the project fostered the improvement of their understanding ($p<0.001$) and capacity to critically reflect about the issues discussed ($p<0.001$). Although considering that some effort was required for the successful completion of the activities ($p=0.002$), they did not perceive the tasks proposed as too difficult ($p=0.69$). *Supporting information Table VI.S4* summarises the participants' mean responses to the feedback questionnaire.

The opportunity to practice new techniques and procedures ($n=25$), to learn more about antibiotics and bacteria ($n=23$), and the good environment and interaction that took place ($n=6$), were highlighted as the most positive features of the project. In contrast, thirteen participants reported that the quality of the project could be improved by further increasing its practical component.

Discussion

The project Microbiology recipes: antibiotics à la carte was a weeklong hands-on program designed to enhance the participants' understanding about bacteria, antibiotics and antibiotic resistance. In line with this main goal, the data gathered reveals that this project provided the participants with a more elaborate picture of antibiotic resistance, by retooling them with more accurate conceptions about the interaction between bacteria and antibiotics, increasing their awareness about the perils of antibiotic resistance, and enabling them to bring into the equation a range of personal mitigating actions.

The quality of the participants' responses was indicative of increased reasoning competencies (*Supporting information - Table VI.S2*). Whereas high school students have been shown to have some difficulties in explaining biologic phenomena involving complex cause-effect relationships (Peker & Wallace, 2009), the participants were able to mobilise notions that were not conveyed in the beginning of the project. They were able to cross-link elements that suggest a more thorough appraisal of individual actions to address some of the questions raised (as illustrated in *Supporting information - Table VI.S3*). This was a very interesting outcome, considering that the main goal of the project was not to induce rote learning, but to empower the participants with concepts and scientifically sustained lines of reasoning to inform their decisions. That is why most questions allowed for responses within both the lower and higher levels of cognition defined by Bloom (Crowe et al., 2008; Lord & Baviskar, 2007). Even if some only evoked knowledge and understanding (Q1, Q2, Q3, Q5 and Q8, *Supporting information Table VI.S1*), others also demanded analysis, synthesis and evaluation, among other competencies (Q4, Q6, Q7, Q9, Q10 and Q11, *Supporting information Table VI.S1*). As discussed in Lord & Baviskar (2007), these emerged from the participants' responses integrated in a continuum.

Previous studies have documented an array of misconceptions about bacteria, namely the confusion between these and other microorganisms, and the overestimation of their harmful effects (Bandiera, 2007; Byrne, 2011; Davey et al., 2002; Milandri, 2004; Simonneaux, 2000). At the beginning of the project, many participants already defined bacteria as unicellular, prokaryotic microorganisms, which is not surprising, given that they had just finished the 10th and 11th grades, the instructional levels in which the Portuguese biology curriculum comprises contents related with cell structure, uni-/multicellularity (DGIDC, 2001), taxonomy and classification (DGIDC, 2003). What is interesting to find is that there was an increase in the quality of the definitions of bacteria provided by most of them at the end of the project. This is particularly important, considering that misconceptions about this notion can lead to misinformed behaviours (Brookes-Howell et al., 2011; Buke et al., 2005; Cebotarenco & Bush, 2008). For instance, it has been argued that the use of antibiotics for flu treatment can be a consequence of bacteria and viruses being misperceived as identical microorganisms (Buke et al., 2005; Cebotarenco & Bush, 2008; McNulty et al., 2007a), which is aggravated by a well-described tendency for physicians to prescribe antibiotics as a prophylactic approach to avoid latent and concomitant bacterial infections (Abbo et al., 2011; Coenen et al., 2009). When enquired about the adequacy of using antibiotics for flu treatment, the participants' opinion shifted from the belief that these drugs are a suitable option, to the perception that this would be an inadequate line of treatment.

Contrasting with the reported tendency for bacteria to be associated with illness (Bandiera, 2007; Milandri, 2004), the participants acknowledged from the start that microorganisms can be both beneficial and harmful for humans. Nevertheless, following their participation in the project, they enhanced their repertoire of examples of bacteria that can have either effect. Moreover, whereas in the pre-test many of them believed that antibiotics only target pathogenic microorganisms, they ended up acknowledging that these drugs collaterally hinder part of the human microbiota. Taking into account the generalised lack of awareness towards the susceptibility of these vital communities to antibiotics (Davey et al., 2002), this is a relevant finding, as it may alert about the need to control antibiotic use.

Besides encouraging the use of antibiotics only when strictly necessary, the importance of following the physicians' advice must be stressed, especially in what concerns finishing a full course of treatment (Brookes-Howell et al., 2011; Davey et al., 2002). Having a general picture of the dynamics of bacterial growth can be insightful in this regard. Taking this into account, the bacterial growth curve was extensively discussed with the participants, leading to a substantial improvement of their description of the bacterial growth cycle. Most importantly, they understood that the knowledge about these aspects is necessary for adequate antibiotic use.

The participants' conceptualisation of antibiotics was also improved. Whilst many of them initially neglected the fact that these compounds only act on bacteria, most of them stated clearly in their post-tests that bacteria are the only target for antibiotic drugs. They also realised that each antibiotic has a more or less broad activity spectrum, and that their specificity is not limited to a particular bacterial species. Beyond providing the participants with a notion of what antibiotics are and how they act, the project was designed to evidence difficulties in counteracting and mitigating antibiotic resistance. A deeper evaluation of these difficulties can be obtained by appraising the complexity of the antibiotic production process, especially regarding the time involved, which barely allows keeping in pace with the rapid rate at which resistance spreads (Alanis, 2005; Demain, 2006; Jayaraman, 2009; Saleem et al., 2010). These aspects were emphasised throughout the project, which, based on the data gathered, was shown to enhance the participants' consciousness about the steps and difficulties in the development of new antibiotics.

Public misperceptions about antibiotics and bacteria extend to antibiotic resistance, which is often regarded as a feature of the host and not of the bacterium (Brookes-Howell et al., 2011; Davey et al., 2002). To some extent contrasting with these reports, most of the participants were reasonably aware that antibiotic resistance refers to bacteria and not humans. But by the end of the project all of them acknowledged this aspect. Moreover, they called attention to the existence of resistance-related genes that can be transferred between bacteria. However, their success in answering correctly to question Q11 ("Do you agree with the statement: The progeny of antibiotic resistant bacteria is also resistant? Justify your answer") was limited, since the distinction between horizontal and vertical gene transfer was somewhat misapprehended. Drawing on the weight of evidence pointing towards the major role of horizontal gene transfer in the dissemination of antibiotic resistance (Hawkey, 1998; Jayaraman, 2009), the project stressed the idea that antibiotic resistance genes can be interchanged between phylogenetically unrelated bacteria subjected to the selective pressure introduced by the same antibiotic (Juhas et al., 2009). The fact that this notion was not consistently manifested in the participants' responses, suggests that some fine-tune adaptations of the instructional design and/or of the measurement instruments are required in future editions of the project. The participants were able to link antibiotic resistance with the improper use of antibiotics, which is a promising outcome, even if this improved understanding may not necessarily translate into adequate behaviours in this scope (Buket et al., 2005; McNulty et al., 2007b).

The participants became more aware of measures to contain antibiotic resistance. Besides recognising that the misuse and overuse of antibiotics has increased the number and diversity of resistant bacteria, they stressed the shortening of effective antibiotics and the difficulties in developing new ones. This awareness expectably fosters the recognition that judicious antibiotic use is fundamental (Alanis, 2005; Davey et al., 2002; Grigoryan et al., 2007). Consistently, there were also noticeable changes in the participants' beliefs about personal actions to address resistance. Interestingly, they went from identifying the production of new antibiotics as the only solution, to summarising a series of individual behaviours that they though must be stimulated, as for instance avoiding self-medication, respecting the physician's instructions, and reducing use. This outcome suggests that the project fostered the participants' sense of self-responsibility, an essential condition for the success of any initiative aimed at promoting rational antibiotic use (Davey et al, 2002).

Concerning the factors underlying the effectiveness of this project, it is important to consider the influence of two major elements: the project's instructional design and the environment in which it was implemented. This project has a marked hands-on character sustained by a meaningful and up-to-date body of scientific data and theory. In its design, particular attention was given to the balance and alignment of both components in each of the activities proposed. In fact, this aspect was highlighted by the participants, who expressed their satisfaction about the way in which practice and theory were integrated. Well contextualised practical activities are known to foster the ability to connect observable and conceptual dimensions (Abrahams, 2011; Rudduck & McIntyre, 2007; Wellington, 2005). Given that the project addresses biological processes that occur at microscopic and molecular levels, a possible explanation for the improvement of the participants' conceptual understanding rests on the scaffolding provided by the visual outcomes and the diversified set of procedures involved in the activities. Amongst its educational benefits, practical work is also expected to promote learning indirectly, by enhancing students' interest (Hofstein & Lunetta, 2003; Knox, Moynihan & Markowitz, 2003; Markowitz, 2004; Toplis, 2011). Accordingly, this project was intended to stimulate the participants' short-term engagement with the contents and procedures, aiming to prompt their learning. Besides the observational field notes collected, the participants' feedback reinforces the role of the practical tasks in engaging them in the activities. They mentioned that they valued the opportunity to practice their procedural skills, which is particularly important considering that most students do not get the chance to carry out practical work at their own schools (Braund & Reiss, 2006; Knox et al., 2003). Furthermore, given that they consistently emphasised the interest and appeal of the activities, it is possible that this factor contributed to the improvement of their knowledge and understanding. It must be kept in mind that this interest was most likely situational (Abrahams & Millar, 2009; Krapp & Prenzel, 2011), deriving from the environment surrounding the participants. The summer school setting in which the project was implemented constitutes a key situational element that must be accounted for. UJr's educational goals are placed within an informal, friendly, and relaxing environment of engagement and interaction, allowing it to be regarded as an educational leisure context (Packer & Ballantyne, 2004). Studies have shown that these contexts Harbor privileged opportunities for social interaction between the students, which may have a beneficial impact on their experience and learning (Packer & Ballantyne, 2004; Rudduck & McIntyre, 2007; Toplis, 2011). Interestingly, many participants viewed the project precisely as an opportunity to interact with their peers, monitors and researchers, and associated this aspect with its success.

Finally, this study raises several questions that are worth pursuing in future research. Based on the observations conducted, extending the study to a broader universe, focusing on diverse age groups, instructional levels and curricular backgrounds, should facilitate general conclusions. To avoid sampling biases, it would be particularly useful to implement the project in a formal classroom context. This was a case study with a small sample of high school science students who personally decided to enrol in the project. Therefore, although statistically significant results were obtained, these do not exclude the chance that these students might already nurture a personal interest about this topic, which might have made them more prone to engage in the activities. Nevertheless, this did not manifest in their baseline knowledge, which was not particularly robust. In turn, it raises the question of whether the magnitude of the improvements in the participants' understanding would be identical if their baseline knowledge was sounder. It is also important to take into account that the project was implemented in a summer school setting, which, as mentioned above, can have impacted positively on the participants' interest and learning. Implementing the project in formal settings would not only permit addressing this issue, but it would also grant the chance to embed the activities and contents in the students' science curriculum, in articulation with the other school subjects. This should enable to distinguish the effects of traditional instruction practices from the outcomes of the activities. Having this in mind, the project's activities can be easily adapted and implemented in schools. Moreover, besides being contextualised in the Portuguese biology curricula (DGIDC, 2001, 2003), the concepts addressed are covered in science curricula from other countries, including the National Science Education Standards (NRC, 1996).

Another aspect to consider relates to the subjective nature of the qualitative data gathered through the open-ended questions in the pre- and post-tests. Although these were required to identify subtle variations in the quality of the participants' reasoning (Oppenheim, 1992), their interpretation is open to subjectivity, regardless of the thoroughness of the content analysis performed. The notions provided by the participants in response to the tests used in this study can be applied to the development of closed questions to be used in future quantitative studies.

Future research could also look into the influence of the project on the participants' antibiotic use behaviours. This study was set up following a pre-/post-test design, in which the post-test was applied immediately after the completion of the project. Therefore, the findings must not be extrapolated beyond its framework. Especially considering that the study was not devised to evaluate long-term retention of information, and the improvements identified in the participants' knowledge and understanding do not necessarily imply positive modifications on their antibiotic use behaviours. In fact, the association between knowledge about antibiotics and antibiotic use is not utterly demonstrated, given the contrasting evidence conveyed in different studies (Buke et al., 2005; Cebotarenco & Bush, 2008; McNulty et al., 2007b). The assessment of this specific dimension can be achieved through a long-term longitudinal study to track the impact of these activities by the time these teenagers reach adulthood and engage in decision-making concerning antibiotic use.

Overall, this and other projects alike represent a contribution to enhance the consciousness about judicious antibiotic use amongst future generations. In addition, the insights made available in this study extend beyond the topic specificity of the project, by evidencing the educational benefits of incorporating hands-on activities in science education programs.

Acknowledgments

The authors are grateful to all the participants in Microbiology recipes: antibiotics à la carte, and to the Reviewers for their thorough reviews and comments. This work was funded by a research grant (PTDC/AGR-PRO/111857/2009) from FCT. MJF and CLS are supported by the FCT fellowships SFRH/BD/37389/2007 and SFRH/BPD/62978/2009, respectively.

References

Abbo, L., Sinkowitz-Cochran, R., Smith, L., Ariza-Heredia, E., Gomez-Marin, O., Srinivasan, A., & Hooton, T. M. (2011). Faculty and resident physicians' attitudes, perceptions, and knowledge about antimicrobial use and resistance. *Infection Control and Hospital Epidemiology, 32*(7), 714-718.

Abrahams, I. (2011). *Practical work in secondary science: a minds-on approach*. London, New York: Continuum International Publishing Group.

Abrahams, I., & Millar, R. (2009). Does practical work really work? A study of the effectiveness of practical work as a teaching and learning method in school science. *International Journal of Science Education, 30*(14), 1945-1969.

Alanis, A. J. (2005). Resistance to antibiotics: Are we in the post-antibiotic era? *Archives of Medical Research, 36*, 697-705.

Bandiera, M. (2007). Micro-organisms: Everyday knowledge predates and contrasts with school knowledge. In R. Pintó & D. Couso (Eds.), *Contributions from Science Education Research* (pp. 213-224). Dordrecht, The Netherlands: Springer Netherlands.

Belongia, E. A., Knobloch, M. J., Kieke Jr, B. A., Davis, J. P., Janette, C., & Besser, R. E. (2005). Impact of statewide program to promote appropriate anitmicrobial drug use. *Emerging Infectious Diseases*, *11*, 912-920.

Braund, M., & Reiss, M. (2006). Validity and worth in the science curriculum: learning school science outside the laboratory. *Curriculum Journal, 17*(3), 213 - 228.

Brookes-Howell, L., Elwyn, G., Hood, K., Wood, F., Cooper, L., Goossens, H., . . . Butler, C. (2011). 'The body gets used to them': Patients' interpretations of antibiotic resistance and the implications for containment strategies. *Journal of General Internal Medicine*, 1-7.

Buke, C., Hosgor-Limoncu, M., Ermertcan, S., Ciceklioglu, M., Tuncel, M., Köse, T., & Eren, S. (2005). Irrational use of antibiotics among university students. *Journal of Infection, 51*(2), 135-139.

Byrne, J. (2011). Models of micro-organisms: Children's knowledge and understanding of micro-organisms from 7 to 14 years old. *International Journal of Science Education, 33*(14), 1927-1961.

Cebotarenco, N., & Bush, P.J. (2008). Reducing antibiotics for colds and flu: a student-taught program. Health Education Research, *23*(1), 146-157.

Coenen, S., Muller, A., Adriaenssens, N., Vankerckhoven, V., Hendrickx, E., & Goossens, H. (2009). European surveillance of antimicrobial consumption (ESAC): Outpatient parenteral antibiotic treatment in Europe. *Journal of Antimicrobial Chemotherapy, 64*(1), 200-205.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. New Jersey: Lawrence Erlbaum.

Cohen, L., Manion, L., & Morrison, K. (2011). *Research methods in education*. Abingdon, Oxon; New York: Routledge Falmer.

Crowe, A., Dirks, C., & Wenderoth, M. P. (2008). Biology in Bloom: implementing Bloom's taxonomy to enhance student learning in biology. *CBE-Life Sciences Education, 7*(4), 368-381.

Davey, P., Pagliari, C., & Hayes, A. (2002). The patient's role in the spread and control of bacterial resistance to antibiotics. *Clinical Microbiology & Infection, 8*(s2), 43-68.

Demain, A. (2006). From natural products discovery to commercialization: a success story. *Journal of Industrial Microbiology and Biotechnology, 33*(7), 486-495.

Direcção-Geral de Inovação e de Desenvolvimento Curricular. (2001). *Programa de biologia e geologia 10º ou 11º anos*. Lisboa, Portugal: Ministério da Educação.

Direcção-Geral de Inovação e de Desenvolvimento Curricular. (2003). *programa de biologia e geologia 11º ou 12º anos*. Curso científico-humanístico de ciências e tecnologias. Lisboa, Portugal: Ministério da Educação.

Direcção-Geral de Inovação e de Desenvolvimento Curricular. (2004). *Programa de biologia 12º ano. curso científico-humanístico de ciências e tecnologias.* Lisboa: Ministério da Educação.

Finkelstein, J. A., Huang, S. S., Kleinman, K., Rifas-Shiman, S. L., Stille, C.J., Daniel, J., …Platt, R. (2008). Impact of a 16-community trial to promote judicious antibiotic use in Massachusetts. *Pediatrics*, *121*(1), e15-e23.

Fonseca, M. J., & Tavares, F. (2011). Natural antibiotics: a hands-on activity on garlic's antibiotic properties. *American Biology Teacher, 73*(6), 342-346.

Goodwin, C. J. (2009). *Research in psychology: Methods and design*. Hoboken, NJ: John Wiley & Sons.

Gravetter, F. J., & Forzano, L. B. (2009). *Research methods for the behavioral sciences*. Belmont, CA: Wadsworth Cengage Learning.

Grigoryan, L., Burgerhof, J. G. M., Degener, J. E., Deschepper, R., Lundborg, C. S., Monnet, D. L., … Haaijer-Ruskamp, F. M. (2007). Attitudes, beliefs and knowledge concerning antibiotic use and self-medication: a comparative European study. *Pharmacoepidemiology and Drug Safety*, *16(11),* 1234-1243.

Hawkey, P. M. (1998). The origins and molecular basis of antibiotic resistance. *British Medical Journal, 317*(7159), 657-660.

Hill, T., & Lewicki, P. (2006). *Statistics: methods and applications : a comprehensive reference for science, industry, and data mining*. Tulsa, OK: StatSoft Inc.

Hofstein, A., & Lunetta, V. N. (2003). The laboratory in science education: foundations for the twenty-first century. *Science Education, 88*(1), 28-54.

Huttner, B., Goossens, H., Verheij, T., & Harbarth S (2010) Characteristics and outcomes of public campaigns aimed at improving the use of antibiotics in outpatients in high-income countries. *The Lancet Infectious Diseases, 10*(1), 17-31.

Jayaraman, R. (2009). Antibiotic resistance: an overview of mechanisms and a paradigm shift. *Current Science, 96*(11), 1475-1484.

Jones, M. G., & Rua, M. J. (2008). Conceptual representations of flu and microbial illness held by students, teachers, and medical professionals. *School Science and Mathematics, 108*(6), 263-278.

Juhas, M., Van Der Meer, J. R., Gaillard, M., Harding, R. M., Hood, D. W., & Crook, D. W. (2009). Genomic islands: tools of bacterial horizontal gene transfer and evolution. *FEMS Microbiology Reviews, 33*(2), 376-393.

Knox, K. L., Moynihan, J. A., & Markowitz, D. G. (2003). Evaluation of short-term impact of a high school Summer science program on students perceived knowledge and skills. *Journal of Science Education and Technology, 12*(4), 471-478.

Krapp, A., & Prenzel, M. (2011). Research on interest in science: Theories, methods, and findings. *International Journal of Science Education, 33*(1), 27 - 50.

Krippendorff, K. (2004). *Content analysis: an introduction to its methodology*. Thousand Oaks, CA: Sage Publications, Inc.

Krist, A. C., & Showsh, S. A. (2007). Experimental evolution of antibiotic resistance in bacteria. *American Biology Teacher, 69*(2), 94-97.

Lecky, D. M., McNulty, C. A. M., Touboul, P., Herotova, T. K., Beneš, J., Dellamonica, P., . . . Weinberg, J. (2010). Evaluation of e-Bug, an educational pack, teaching about prudent antibiotic use and hygiene, in the Czech Republic, France and England. *Journal of Antimicrobial Chemotherapy, 65*(12), 2674-2684

Longtin, S., Guilfoile, P., & Asper, A. (2004). Genotypic detection of antibiotic resistance in Escherichia coli: a classroom exercise. *Journal of Biological Education, 39*, 32-34.

Lord, T., & Baviskar, S. (2007). Moving students from information recitation to information understanding: Exploiting Bloom's Taxonomy in creating science questions. *Journal of College Science Teaching, 36*(5), 40-44.

Markowitz, D. G. (2004). Evaluation of the long-term impact of a university high school summer science program on students' interest and perceived abilities in science. *Journal of Science Education and Technology, 13*(3), 395-407.

McNulty, C. A. M., Boyle, P., Nichols, T., Clappison, P., & Davey, P. (2007a). The public's attitudes to and compliance with antibiotics. *Journal of Antimicrobial Chemotherapy, 60*(1), 63-68.

McNulty, C. A. M., Boyle, P., Nichols, T., Clappison, P., & Davey, P. (2007b). Don't wear me out--the public's knowledge of and attitudes to antibiotic use. *Journal of Antimicrobial Chemotherapy, 59*(4), 727-738

Milandri, M. (2004). Children's views of microbes - Current beliefs about bacteria in Italian grade school children. *Pediatric Infectious Disease Journal, 23*(12), 1077-1080.

Mölstad, S., Erntell, M., Hanberger, H., Melander, E., Norman, C., Skoog, G., …Cars, O. (2008). Sustained reduction of antibiotic use and low bacterial resistance: 10-year follow-up of the Swedish Strama programme. *The Lancet Infectious Diseases*, *8*(2), 125-132.

Moore, B., & Stanley, T. (2009). *Critical thinking and formative assessments: increasing the rigor in your classroom*. Larchmont, NY: Eye on Education.

National Research Council. (1996). *National science education standards*. Washington, DC: National Academy Press.

Oppenheim, A. N. (1992). *Questionnaire design, interviewing and attitude measurement*. London, New York, Continuum.

Orzech, K. M., & Nichter, M. (2008). From resilience to resistance: Political ecological lessons from antibiotic and pesticide resistance. *Annual Review of Anthropology*, *37*(1), 267-282.

Packer, J., & Ballantyne, R. (2004). Is educational leisure a contradiction in terms? Exploring the synergy of education and entertainment. *Annals of Leisure Research, 7*(1), 54-71.

Peker, D., & Wallace, C. (2009). Characterizing high school students' written explanations in biology laboratories. *Research in Science Education*, 1-23.

Rudduck, J., & McIntyre, D. (2007). *Improving learning through consulting pupils*. New York: Routledge.

Sabuncu, E., David, J., Bernède-Bauduin, C., Pépin, S., Leroy, M., Boëlle, P., …Guillemot, D. (2009). Significant reduction of antibiotic use in the community after a nationwide campaign in France, 2002–2007. PLoS Medicine. *6*(6), e1000084.

Saleem, M., Nazir, M., Ali, M. S., Hussain, H., Lee, Y. S., Riaz, N., & Jabbar, A. (2010). Antimicrobial natural products: an update on future antibiotic drug candidates. *Natural Product Reports, 27*(2), 238-254.

Schunk, D.H., & Mullen, C.A. (2012). Self-efficacy as an engaged learner. In: S.L. Christenson, A.L. Reschly, & C. Wylie (Eds.). *Handbook of research on student engagement* (pp. 219-236).New York, Dordrecht, Heidelberg, London: Springer.

Simonneaux, L. (2000). A study of pupils' conceptions and reasoning in connection with 'microbes', as a contribution to research in biotechnology education. *International Journal of Science Education, 22*, 619-644.

Tibell, L. A. E., & Rundgren, C.-J. (2010). Educational challenges of molecular life science: characteristics and implications for education and research. *CBE-Life Sciences Education, 9*(1), 25-33

Toplis, R. (2011). Students' views about secondary school science lessons: The role of practical work. *Research in Science Education, 42*(3), 1-19.

van de Sande-Bruinsma, N., Grundmann, H., Verloo, D., Tiemersma, E., Monen, J., Goossens, H., & Ferech, M. (2008). Antimicrobial drug use and resistance in Europe. *Emerging Infectious Disesases*, *14,* 1722-1832.

Wassmer, G. T., Kipe-Nolt, J. A., & Chayko, C. A. (2006). Why finish your antibiotics? A novel, hands-on, classroom approach for teaching the dynamics of antibiotic resistance. *American Biology Teacher, 68*(8), 476-480.

Weber, R. P. (1990). *Basic content analysis*. Newbury Park, CA: Sage Publications, Inc.

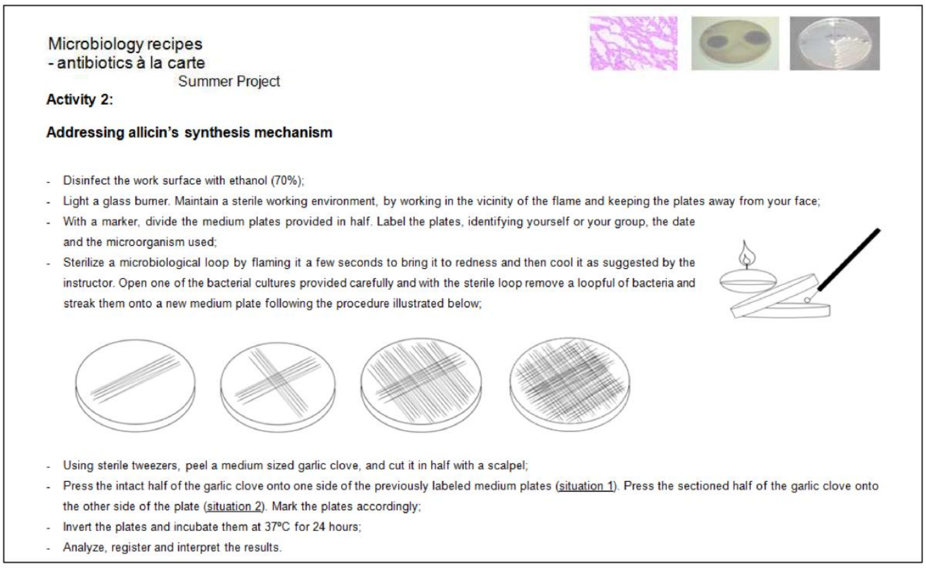
Weil, D. K., & Kincheloe, J. L. (2004). *Critical thinking and learning: an encyclopedia for parents and teachers*. Westport, CT: Greenwood Press.

Wellington, J. (2005). Practical work and the affective domain: What do we know, what should we ask, and what is worth exploring further? In S. Aslop (Ed.), *Beyond cartesian dualism. Encountering affect in the teaching and learning science* (pp. 99-110). Dordrecht: Springer.

World Health Organization. (2000). WHO Annual report on infectious disease: overcoming antimicrobial resistance. Geneva, Switzerland: World Health Organization. Available: http://www.who.int/infectious-disease-report/2000/. Accessed: 17 December 2011.

Supporting information

A



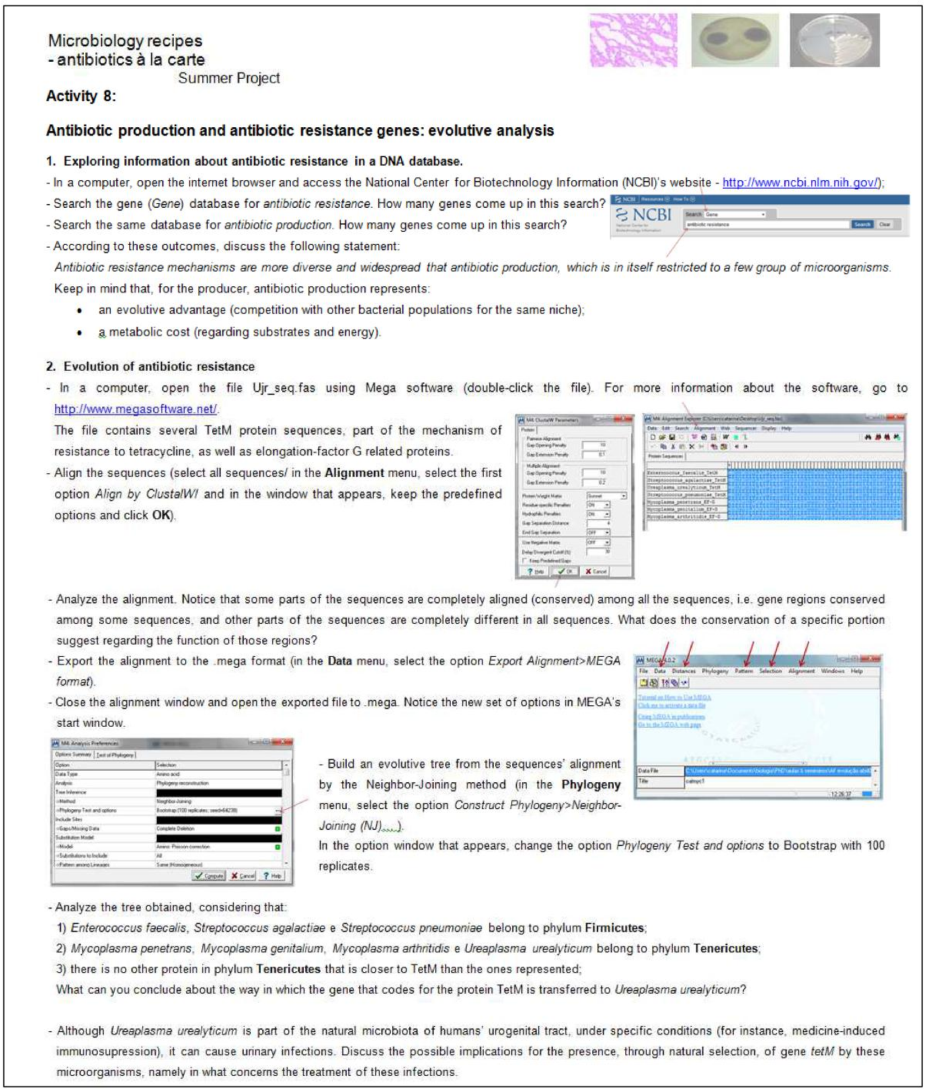
Microbiology recipes
- antibiotics à la carte
Summer Project

Activity 2:

Addressing allicin's synthesis mechanism

- Disinfect the work surface with ethanol (70%);
- Light a glass burner. Maintain a sterile working environment, by working in the vicinity of the flame and keeping the plates away from your face;
- With a marker, divide the medium plates provided in half. Label the plates, identifying yourself or your group, the date and the microorganism used;
- Sterilize a microbiological loop by flaming it a few seconds to bring it to redness and then cool it as suggested by the instructor. Open one of the bacterial cultures provided carefully and with the sterile loop remove a loopful of bacteria and streak them onto a new medium plate following the procedure illustrated below;
- Using sterile tweezers, peel a medium sized garlic clove, and cut it in half with a scalpel;
- Press the intact half of the garlic clove onto one side of the previously labeled medium plates (situation 1). Press the sectioned half of the garlic clove onto the other side of the plate (situation 2). Mark the plates accordingly;
- Invert the plates and incubate them at 37ºC for 24 hours;
- Analyze, register and interpret the results.

B



Microbiology recipes
- antibiotics à la carte
Summer Project

Activity 8:

Antibiotic production and antibiotic resistance genes: evolutive analysis

1. Exploring information about antibiotic resistance in a DNA database.

- In a computer, open the internet browser and access the National Center for Biotechnology Information (NCBI)'s website - http://www.ncbi.nlm.nih.gov/);
- Search the gene (*Gene*) database for *antibiotic resistance*. How many genes come up in this search?
- Search the same database for *antibiotic production*. How many genes come up in this search?
- According to these outcomes, discuss the following statement:
Antibiotic resistance mechanisms are more diverse and widespread that antibiotic production, which is in itself restricted to a few group of microorganisms.
Keep in mind that, for the producer, antibiotic production represents:
  - an evolutive advantage (competition with other bacterial populations for the same niche);
  - a metabolic cost (regarding substrates and energy).

2. Evolution of antibiotic resistance

- In a computer, open the file Ujr_seq.fas using Mega software (double-click the file). For more information about the software, go to http://www.megasoftware.net/.
The file contains several TetM protein sequences, part of the mechanism of resistance to tetracycline, as well as elongation-factor G related proteins.
- Align the sequences (select all sequences/ in the **Alignment** menu, select the first option *Align by ClustalW/* and in the window that appears, keep the predefined options and click **OK**).
- Analyze the alignment. Notice that some parts of the sequences are completely aligned (conserved) among all the sequences, i.e. gene regions conserved among some sequences, and other parts of the sequences are completely different in all sequences. What does the conservation of a specific portion suggest regarding the function of those regions?
- Export the alignment to the .mega format (in the **Data** menu, select the option *Export Alignment>MEGA format*).
- Close the alignment window and open the exported file to .mega. Notice the new set of options in MEGA's start window.
- Build an evolutive tree from the sequences' alignment by the Neighbor-Joining method (in the **Phylogeny** menu, select the option *Construct Phylogeny>Neighbor-Joining (NJ)....*).
In the option window that appears, change the option *Phylogeny Test and options* to Bootstrap with 100 replicates.
- Analyze the tree obtained, considering that:
1) *Enterococcus faecalis*, *Streptococcus agalactiae* e *Streptococcus pneumoniae* belong to phylum **Firmicutes**;
2) *Mycoplasma penetrans*, *Mycoplasma genitalium*, *Mycoplasma arthritidis* e *Ureaplasma urealyticum* belong to phylum **Tenericutes**;
3) there is no other protein in phylum **Tenericutes** that is closer to TetM than the ones represented;
What can you conclude about the way in which the gene that codes for the protein TetM is transferred to *Ureaplasma urealyticum*?
- Although *Ureaplasma urealyticum* is part of the natural microbiota of humans' urogenital tract, under specific conditions (for instance, medicine-induced immunosupression), it can cause urinary infections. Discuss the possible implications for the presence, through natural selection, of gene *tetM* by these microorganisms, namely in what concerns the treatment of these infections.

Fig. VI.S1. Two examples of protocols provided to the participants.

These protocols illustrate some procedures conducted in the scope of a (A) wet lab activity and a (B) dry lab activity. See Fig. VI.1 for the full list of activities implemented.

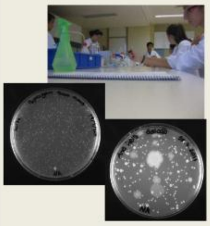
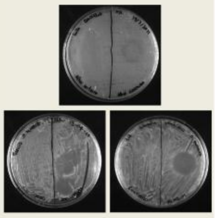
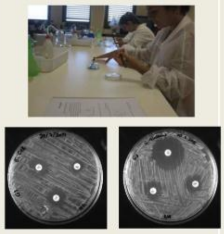
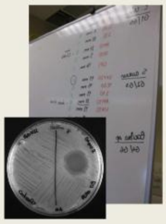
Time	Monday	Tuesday	Wednesday	Thursday	Friday
9.00 12.30	• Introduction • Pre-test • Lecture – “Microbiology recipes: antibiotics à la carte” • Safety recommendations 	• Observation and discussion of results • Practical – Allicin’s synthesis mechanism 	• Observation and discussion of results • Practical - Growth media preparation and sterilization 	• Practical – Bioassays (plant extracts; preparation of antibiograms using commercial antibiotics) 	• Observation and discussion of results • Preparation of activity reports 
Lunch					
14.00 17.30	• Lecture (cont.) • Analysis of scientific papers • Practical - Bacterial culture and isolation techniques 	• Lecture – “Meet *Bacillus cereus*” • Practical - Microscopic observation of bacteria 	• Practical (cont.) - Growth media platting • Practical – Plant extract preparation 	• Lecture – “A bioinformatics approach to molecular evolution” • Practical - A bioinformatics approach to the study of antibiotic resistance 	• Presentation and discussion of the reports • Post-test • Feedback questionnaires 

Fig. VI.S2. Microbiology recipes: antibiotics à la carte project plan.
The activities were implemented as suggested in this figure, although their schedule and planning can be adapted and altered.

Table VI.S1

Pre-/post-test and scoring rubrics used to assess the participants' understanding and beliefs about bacteria, antibiotics and antibiotic resistance.

Q1. How do you define bacteria?

Bloom's Level	Criteria	Points	Qualitative classifier
Knowledge (LO) Comprehension (LO)	• No answer • Only incorrect notions • More incorrect than correct notions (one or two notions)	0	Inadequate/ failing effort
	• Only one correct notion • Two correct notions and one incorrect • More incorrect than correct notions (three or more notions)	1	Impaired/ minimum effort
	• Same amount of correct and incorrect notions (three or more notions) • Two correct notions and none incorrect	2	Needs much improvement/ low effort
	• More correct than incorrect notions (three or more notions)	3	Needs improvement/ effort
	• Three or more correct notions and none incorrect (only notions related with bacteria morphology and phylogeny, e.g. microorganism, prokaryote)	4	Adequate/ good effort
	• Three or more correct notions and none incorrect (including notions related with bacteria physiology and activity, e.g. pathogenic, antibiotic resistant)	5	High achievement/ high effort

Q2. Are bacteria beneficial or harmful for humans? Give some illustrative examples.

Bloom's Level	Criteria	Points	Qualitative classifier
Knowledge (LO) Comprehension (LO)	• No answer • None example or justification or both incorrect • One or two correct examples and one incorrect • Bacteria as exclusively beneficial/ harmful, one correct and one incorrect example	0	Inadequate/ failing effort
	• Bacteria as beneficial and/or harmful, and one correct example • Bacteria as exclusively beneficial/ harmful, and more correct than incorrect examples (two or more examples)	1	Impaired/ minimum effort
	• Bacteria as exclusively beneficial/ harmful, and the same amount of correct and incorrect examples (two or more examples) • Bacteria as beneficial and harmful, and one correct example or more incorrect than correct examples (two or more examples)	2	Needs much improvement/ low effort
	• Bacteria as exclusively beneficial/ harmful, and more correct than incorrect examples (two or more examples) • Bacteria as beneficial and harmful, and the same amount of correct and incorrect examples (two or more examples)	3	Needs improvement/ effort
	• Bacteria as exclusively beneficial/ harmful, two or more correct examples and none incorrect • Bacteria as beneficial and harmful, and more correct than incorrect examples (two or more examples)	4	Adequate/ good effort
	• Bacteria as beneficial and harmful, three to six correct examples, and none incorrect	5	High achievement/ high effort
	• Bacteria as beneficial and harmful, more than six correct examples, and none incorrect	6	Outstanding achievement/ very high effort

"Don't know" answers were considered as "No answer" and attributed no points. See *Supporting information - Table VI.S3* for examples of notions conveyed in the pre- and post-test.

Table VI.S1 (continued)

Q3. Describe the main phases in bacteria's growth cycle.			
Bloom's Level	Criteria	Points	Qualitative classifier
Knowledge (LO) Comprehension (LO)	• No answer • Only incorrect notions • Identification of one or two phases, but no description	0	Inadequate/ failing effort
	• Identification and description (or only description) of one or two phases • One or more correct notions	1	Impaired/ minimum effort
	• Identification and description (or only description) of one or two phases, and one or more correct notions • Identification of three phases, and one or more correct notions • Identification and description of three phases, but one or more incorrect notions • Identification of four phases, but one or more incorrect notions	2	Needs much improvement/ low effort
	• Identification and description of three phases, or identification of four phases	3	Needs improvement/ effort
	• Identification and description of three phases, or identification of the four phases, and two or more correct notions	4	Adequate/ good effort
	• Identification and description (or only description) of the four phases, two or more correct notions, but some incorrect notions as well	5	High achievement/ high effort
	• Identification and description of the four phases and two or more correct notions	6	Outstanding achievement/ very high effort
Q4. Do you think that bacterial infectious diseases are currently under control? Justify your answer.			
Bloom's Level	Criteria	Points	Qualitative classifier
Knowledge (LO) Comprehension (LO) Application (HO) Synthesis (HO) Evaluation (HO)	• No answer • No justification or only inadequate justifications	0	Inadequate/ failing effort
	• Valid and coherent explanation with one adequate claim	1	Needs much improvement/ low effort
	• Valid and coherent explanation with two or three adequate claims	2	Adequate/ good effort
	• Valid and coherent explanation with more than three adequate claims	3	High achievement/ high effort
Q5. How do you define antibiotics?			
Bloom's Level	Criteria	Points	Qualitative classifier
Knowledge (LO) Comprehension (LO)	• No answer • Only incorrect notions • More incorrect than correct notions (one or two notions)	0	Inadequate/ failing effort
	• Only one correct notion • Two correct notions and one incorrect • More incorrect than correct notions (three or more notions)	1	Impaired/ minimum effort
	• Same amount of correct and incorrect notions (three or more notions) • Two correct notions and none incorrect	2	Needs much improvement/ low effort
	• More correct than incorrect notions (three or more notions)	3	Needs improvement/ effort
	• Three to five correct notions and none incorrect	4	Adequate/ good effort
	• More than five correct notions and none incorrect	5	High achievement/ high effort

"Don't know" answers were considered as "No answer" and attributed no points. See *Supporting information - Table VI.S3* for examples of notions conveyed in the pre- and post-test.

Table VI.S1 (continued)

Q6. How do you explain the selectivity of antibiotics for microorganisms?			
Bloom's Level	Criteria	Points	Qualitative classifier
Knowledge (LO) Comprehension (LO) Application (HO) Evaluation (HO)	• No answer • Only incorrect notions • One or two correct notions but more than two incorrect notions	0	Inadequate/ failing effort
	• Only one correct notion • Two correct and two incorrect notions	1	Impaired/ minimum effort
	• Two correct notions and one incorrect	2	Needs much improvement/ low effort
	• Suitable response with two correct notions (difference between prokaryotic and eukaryotic cells, specificity and concentration of antibiotic compounds)	3	Adequate/ good effort
Q7. Imagine that you have the flu, you are feverish and aching. In this situation, do you think that antibiotic prescription would be a suitable solution? Justify your answer.			
Bloom's Level	Criteria	Points	Qualitative classifier
Knowledge (LO) Comprehension (LO) Application (HO) Synthesis (HO) Evaluation (HO)	• No answer • Yes or No without justification	0	Inadequate/ failing effort
	• Yes, but with adequate justification (e.g. control of concomitant and secondary bacterial infections)	1	Impaired/ minimum effort
	• No, with adequate justification including one correct notion • No, with adequate justification including more than one correct notions, but also one or more incorrect notions	2	Needs much improvement/ low effort
	• No, with adequate justification including only correct notions	3	Adequate/ good effort
Q8. Describe how an antibiotic is produced.			
Bloom's Level	Criteria	Points	Qualitative classifier
Knowledge (LO) Comprehension (LO)	• No answer • Only incorrect notions	0	Inadequate/ failing effort
	• One correct notion • Two or three correct notions, but one or two incorrect	1	Impaired/ minimum effort
	• Two or three correct notions • Four to six correct notions, but two or more incorrect	2	Needs improvement/ effort
	• Four to six correct notions • More than six correct notions, but two or more incorrect	3	Adequate/ good effort
	• More than six correct notions, and none incorrect	4	High achievement/ high effort
	• More than six correct notions, following a reasonable line of reasoning	5	Outstanding achievement/ very high effort

"Don't know" answers were considered as "No answer" and attributed no points. See *Supporting information - Table VI.S3* for examples of notions conveyed in the pre- and post-test.

Table VI.S1 (continued)

Q9. How do you define antibiotic resistance?

Bloom's Level	Criteria	Points	Qualitative classifier
Knowledge (LO) Comprehension (LO) Application (HO)	• No answer • Only incorrect notions • More incorrect than correct notions (one or two notions)	0	Inadequate/ failing effort
	• Only one correct notion • Two correct notions and one incorrect • More incorrect than correct notions (three or more notions)	1	Impaired/ minimum effort
	• Same amount of correct and incorrect notions (three or more notions) • Two correct notions and none incorrect	2	Needs much improvement/ low effort
	• More correct than incorrect notions (three or more notions)	3	Needs improvement/ effort
	• Three or more correct notions and none incorrect (only notions related with the definition of resistance, e.g. a feature of the bacterium, allows bacteria to survive in the presence of the antibiotic compound)	4	Adequate/ good effort
	• Three or more correct notions and none incorrect (including notions related with mechanisms of resistance and transfer of resistance, e.g. alternative metabolic pathways, horizontal and vertical gene transfer)	5	High achievement/ high effort

Q10. List measures that can be used to avoid or reduce antibiotic resistance.

Bloom's Level	Criteria	Points	Qualitative classifier
Knowledge (LO) Application (HO)	• No answer • Only incorrect notions	0	Inadequate/ failing effort
	• Only one correct notion • Two or three correct notions, but one or two incorrect	1	Impaired/ minimum effort
	• Two correct notions and none incorrect • Three or four correct notions, but two or more incorrect	2	Needs improvement/ effort
	• Three or four correct notions and none incorrect • More than five correct notions, but two or more incorrect	3	Adequate/ good effort
	• More than five correct notions and none incorrect	4	High achievement/ high effort

Q11. Do you agree with the statement: *The progeny of antibiotic resistant bacteria is also resistant*. Justify your answer.

Bloom's Level	Criteria	Points	Qualitative classifier
Knowledge (LO) Application (HO) Application (HO) Analysis (HO) Evaluation (HO)	• No answer • Only incorrect notions	0	Inadequate/ failing effort
	• Only one correct notion • Two or three correct notions, but one or two incorrect	1	Impaired/ minimum effort
	• Two correct notions and none incorrect • Three or four correct notions, but two or more incorrect	2	Needs improvement/ effort
	• Three or four correct notions (that may not be the most adequate to fully address the question) and none incorrect • More than four correct notions, but two or more incorrect	3	Adequate/ good effort
	• More than four correct notions (the most adequate to address the question, e. g. There are antibiotic resistance-related genes in the genomic DNA and in the plasmids, while plasmids may not be transmitted to the daughter-cells, genes in the genomic DNA are), but two or more incorrect notions	4	High achievement/ high effort
	• More than four correct notions (the most adequate to address the question) and none incorrect	5	Outstanding achievement/ very high effort

"Don't know" answers were considered as "No answer" and attributed no points. See *Supporting information - Table VI.S3* for examples of notions conveyed in the pre- and post-test.

Table VI.S2

Pre-/post-test variations in the quality of the participants' responses.

Q1. How do you define bacteria?					
			Paired Samples *t*-test		Effect size
		M (*SD*)	*t*(41)	*p*	*d*
Scoring rubric score	Pre-test	1.95 (1.32)	4.86	0.00	0.90
	Post-test	3.19 (1.44))			
Number of correct notions/ response	Pre-test	2.10 (1.36)	3.55	0.00	0.65
	Post-test	3.00 (1.40)			
Number of incorrect notions/ response	Pre-test	0.36 (0.79)	-2.80	0.01	0.53
	Post-test	0.05 (0.22)			
Q2. Are bacteria beneficial or harmful for humans? Give some illustrative examples.					
			Paired Samples *t*-test		Effect size
		M (*SD*)	*t*(41)	*p*	*d*
Scoring rubric score	Pre-test	2.31 (1.73)	5.24	0.00	0.99
	Post-test	3.86 (1.39)			
Number of correct examples of beneficial bacteria/ response	Pre-test	0.69 (0.60)	3.12	0.00	0.62
	Post-test	1.21 (1.03)			
Number of correct examples of harmful bacteria/ responses	Pre-test	0.71 (0.46)	3.47	0.00	0.72
	Post-test	1.19 (0.83)			
Number of incorrect examples of beneficial bacteria/ response	Pre-test	0.14 (0.35)	-1.78	0.08	0.23
	Post-test	0.07 (0.26)			
Number of incorrect examples of harmful bacteria/ response	Pre-test	0.07 (0.26)	-1.78	0.08	0.38
	Post-test	0.00 (0.00)			
Q3. Describe the main phases in bacteria's growth cycle.					
			Paired Samples *t*-test		Effect size
		M (*SD*)	*t*(41)	*p*	*d*
Scoring rubric score	Pre-test	0.19 (0.40)	11.34	0.00	2.62
	Post-test	3.83 (1.92)			
Number of correct notions/ response	Pre-test	0.33 (0.65)	13.97	0.00	3.12
	Post-test	7.17 (3.03)			
Number of incorrect notions/ response	Pre-test	0.21 (0.72)	0.17	0.87	0.04
	Post-test	0.24 (0.73)			
Q4. Do you think that bacterial infectious diseases are currently under control? Justify your answer.					
			Paired Samples *t*-test		Effect size
		M (*SD*)	*t*(41)	*t*(41)	*d*
Scoring rubric score	Pre-test	0.61 (0.77)	5.49	0.00	1.18
	Post-test	1.54 (0.81)			
Number of valid claims to support the response	Pre-test	0.52 (0.67)	6.95	0.00	1.43
	Post-test	1.86 (1.14)			
Number of invalid claims to support the response	Pre-test	0.62 (0.58)	-5.87	0.00	1.06
	Post-test	0.12 (0.33)			
Q5. How do you define antibiotics?					
			Paired Samples *t*-test		Effect size
		M (*SD*)	*t*(41)	*p*	*d*
Scoring rubric score	Pre-test	0.88 (1.21)	7.18	0.00	1.39
	Post-test	2.93 (1.70)			
Number of correct notions/ response	Pre-test	1.14 (0.85)	7.04	0.00	1.42
	Post-test	3.48 (2.13)			
Number of incorrect notions/ response	Pre-test	0.71 (0.71)	-2.47	0.02	0.51
	Post-test	0.38 (0.58)			

M ± SD – Mean ± Standard Deviation. *d* – Cohen's d measure of effect size. The scoring rubrics used to rate the participants' responses can be found in *Supporting information - Table VI.S1*, and a list of notions conveyed in the pre- and post-test is available in *Supporting information - Table VI.S3*.

Table VI.S2 (continued)

Q6. How do you explain the selectivity of antibiotics for microorganisms?

			Paired Samples *t*-test		Effect size
		M (*SD*)	*t*(41)	*p*	*d*
Scoring rubric score	Pre-test	0.17 (0.54)	2.05	0.04	0.39
	Post-test	0.43 (0.77)			
Number of correct notions/ response	Pre-test	0.14 (0.42)	2.71	0.01	0.49
	Post-test	0.40 (0.63)			
Number of incorrect notions/ response	Pre-test	0.12 (0.40)	-1.40	0.17	0.27
	Post-test	0.24 (0.48)			

Q7. Imagine that you have the flu, you are feverish and aching. In this situation, do you think that antibiotic prescription would be a suitable solution? Justify your answer.

			Paired Samples *t*-test		Effect size
		M (*SD*)	*t*(41)	*p*	*d*
Scoring rubric score	Pre-test	0.24 (0.76)	7.10	0.00	1.55
	Post-test	1.81 (1.21)			
Number of correct notions/ response	Pre-test	0.14 (0.47)	6.79	0.00	1.36
	Post-test	1.10 (0.88)			
Number of incorrect notions/ response	Pre-test	0.31 (0.47)	-2.22	0.03	0.33
	Post-test	0.17 (0.38)			

Q8. Describe how an antibiotic is produced.

			Paired Samples *t*-test		Effect size
		M (*SD*)	*t*(41)	*p*	*d*
Scoring rubric score	Pre-test	0.26 (0.70)	7.89	0.00	1.58
	Post-test	1.95 (1.34)			
Number of correct notions/ response	Pre-test	0.33 (0.93)	7.43	0.00	1.49
	Post-test	2.95 (2.30)			
Number of incorrect notions/ response	Pre-test	0.07 (0.26)	1.00	0.32	0.24
	Post-test	0.02 (0.15)			

Q9. How do you define antibiotic resistance?

			Paired Samples *t*-test		Effect size
		M (*SD*)	*t*(41)	*p*	*d*
Scoring rubric score	Pre-test	2.71 (1.94)	4.02	0.00	0.76
	Post-test	3.98 (1.37)			
Number of correct notions/ response	Pre-test	2.33 (1.39)	3.62	0.00	0.77
	Post-test	3.38 (1.34)			
Number of incorrect notions/ response	Pre-test	0.19 (0.40)	-3.11	0.00	0.67
	Post-test	0.00 (0.00)			

M ± SD – Mean ± Standard Deviation. *d* – Cohen's d measure of effect size. The scoring rubrics used to rate the participants' responses can be found in *Supporting information - Table VI.S1*, and a list of notions conveyed in the pre- and post-test is available in *Supporting information - Table VI.S3*.

Table VI.S2 (continued)

Q10. List measures that can be used to avoid or reduce antibiotic resistance.

			Paired Samples *t*-test		Effect size
		M (*SD*)	*t*(41)	*p*	*d*
Scoring rubric score	Pre-test	0.64 (0.73)	8.85	0.00	1.79
	Post-test	2.21 (1.00)			
Number of correct notions/ response	Pre-test	0.67 (0.72)	8.23	0.00	1.72
	Post-test	2.45 (1.27)			
Number of incorrect notions/ response	Pre-test	0.21 (0.42)	-1.16	0.25	0.24
	Post-test	0.12 (0.33)			

Q11. Do you agree with the statement: *The progeny of antibiotic resistant bacteria is also resistant*. Justify your answer.

			Paired Samples *t*-test		Effect size
		M (*SD*)	*t*(41)	*p*	*d*
Scoring rubric score	Pre-test	0.48 (0.74)	3.19	0.00	0.54
	Post-test	1.00 (1.13)			
Number of correct notions/ response	Pre-test	0.52 (0.74)	4.27	0.00	0.73
	Post-test	1.21 (1.12)			
Number of incorrect notions/ response	Pre-test	0.24 (0.43)	2.67	0.01	0.43
	Post-test	0.45 (0.55)			

M ± SD – Mean ± Standard Deviation. *d* – Cohen's d measure of effect size. The scoring rubrics used to rate the participants' responses can be found in *Supporting information - Table VI.S1*, and a list of notions conveyed in the pre- and post-test is available in *Supporting information - Table VI.S3*.

Table VI.S3
Notions and claims provided in the pre-test and in the post-test.

Q1. How do you define bacteria?				
	n		McNemar test	
	Pre-test	Post-test	χ^2	*p*
Correct notions				
Unicellular	21	31	5.06	0.02
Beneficial or harmful	6	16	5.79	0.01
Monera kingdom	6	15	5.82	0.01
Incorrect notions				
Multicellular	6	0	4.17	0.03
Q2. Are bacteria beneficial or harmful for humans? Give some illustrative examples.				
	n		McNemar test	
	Pre-test	Post-test	χ^2	*p*
Correct examples of beneficial bacteria				
Human symbiotic bacteria	10	25	11.53	0.00
Correct examples of harmful bacteria				
Bacillus cereus	0	13	11.08	0.00
Disease	19	7	6.72	0.01
Q3. Describe the main phases in bacteria's growth cycle.				
	n		McNemar test	
	Pre-test	Post-test	χ^2	*p*
Growth phases				
Identification				
Lag	0	27	25.04	0.00
Exponential	0	32	30.03	0.00
Stationary	0	30	28.03	0.00
Death	0	31	29.03	0.00
Four phases	0	29	27.03	0.00
Description				
Lag	0	18	16.06	0.00
Exponential	0	30	28.03	0.00
Stationary	0	28	26.04	0.00
Death	0	28	28.03	0.00
Four phases	0	18	16.06	0.00
Correct notions				
Death	4	29	21.33	0.00
Exponential growth	0	23	21.04	0.00
Influence of the medium conditions	1	13	8.64	0.00
Incorrect notions				
Confusions regarding the lag phase (e.g. "when the bacterium arrives at the medium")	0	6	4.17	0.03

n – number of participants who mentioned the notion. "Don't know" answers were considered as "No answer". A full list of notions provided by the participants is available from the authors upon request.

Table VI.S3 (continued)

Q4. Do you think that bacterial infectious diseases are currently under control? Justify your answer.

	n		McNemar test	
	Pre-test	Post-test	χ^2	*p*
Students answering:				
Yes, bacterial infectious diseases are contained	17	4	9.600	0.00
No, bacterial infectious diseases are not contained	12	31	15.43	0.00
Valid claims				
Bacteria may be resistant to certain antibiotics	5	33	26.04	0.00
Bacteria adapt	2	14	8.64	0.00
The number of efficient antibiotics is limited and it is difficult to develop new ones	1	11	8.10	0.00
Invalid claims				
There are sterilisation mechanisms and information	14	0	12.07	0.00

Q5. How do you define antibiotics?

	n		McNemar test	
	Pre-test	Post-test	χ^2	*p*
Correct notions				
Inhibits bacterial growth	5	29	20.35	0.00
Kills bacteria	6	33	25.04	0.00
Modes of action	1	8	40.00	0.02
Produced by bacteria or fungus	0	7	5.14	0.02
Incorrect notions				
Confusion about bacteriostatic (e.g. "inhibits several metabolic processes in bacteria")	0	6	4.17	0.03

Q6. How do you explain the selectivity of antibiotics for microorganisms?

	n		McNemar test	
	Pre-test	Post-test	χ^2	*p*
Correct notions				
Specificity of action	5	14	5.82	0.01
Incorrect notions				
Confusion between selectivity and spectrum of activity	16	29	7.68	0.00

Q7. Imagine that you have the flu, you are feverish and aching. In this situation, do you think that antibiotic prescription would be a suitable solution? Justify your answer.

	n		McNemar test	
	Pre-test	Post-test	χ^2	*p*
Students answering:				
Yes, antibiotics can be used for flu treatment	17	8	3.77	0.05
No, antibiotics cannot be used for flu treatment	14	32	11.12	0.00
I do not know if antibiotics can be used for flu treatment	11	2	7.11	0.00
Correct notions				
The flu is caused by a virus	1	19	11.45	0.00
Antibiotics act on bacteria	1	17	14.06	0.00
The overuse of antibiotics can lead to increased resistance	0	11	9.09	0.00

n – number of participants who mentioned the notion. “Don’t know” answers were considered as “No answer”. A full list of notions provided by the participants is available from the authors upon request.

Table VI.S3 (continued)

Q8. Describe how an antibiotic is produced.

	n		McNemar test	
	Pre-test	Post-test	χ^2	*p*
Correct notions				
Isolation/ extraction of the compound	2	24	18.38	0.00
Microbiological tests	6	22	14.06	0.00
Concentration of the compound	0	7	5.14	0.02
Animal tests	1	19	16.06	0.00
Purification	0	8	6.13	0.01
Clinical trials	1	22	19.05	0.00
Formulation and commercialisation	2	12	8.10	0.00
Obtained from bacteria	1	20	17.05	0.00
Use of compounds produced in laboratory	0	9	7.11	0.00

Q9. How do you define antibiotic resistance?

	n		McNemar test	
	Pre-test	Post-test	χ^2	*p*
Correct notions				
Feature of the bacterium	31	40	7.11	0.00
Bacteria can adapt	8	20	6.05	0.01
Incorrect notions				
Feature of the host	6	0	4.17	0.03

Q10. List measures that can be used to avoid or reduce antibiotic resistance.

	n		McNemar test	
	Pre-test	Post-test	χ^2	*p*
Correct notions				
Avoid the overuse of antibiotics	10	28	11.12	0.00
Respect the full length of treatment	3	28	23.04	0.00
Avoid self-medication	2	17	11.53	0.00
Respect the physician's instructions	2	16	12.07	0.00

Q11. Do you agree with the statement: *The progeny of antibiotic resistant bacteria is also resistant*. Justify your answer.

	n		McNemar test	
	Pre-test	Post-test	χ^2	*p*
Correct notions				
There are antibiotic resistance-associated genes	8	16	4.08	0.04
Vertical gene transfer	8	24	12.50	0.00
Incorrect notions				
Confusion between vertical and horizontal gene transfer	0	6	4.17	0.03

n – number of participants who mentioned the notion. "Don't know" answers were considered as "No answer". A full list of notions provided by the participants is available from the authors upon request.

Table VI.S4. Participants' feedback on the activity.

		One Sample *t*-test		Effect size
	M ± SD	*t*(41)	*p*	*d*
Difficulty of the contents	3.07±0.71	0.65	0.52	0.14
Interest of the contents	4.52±0.55	17.90	0.00	3.91
Organisation and structuring of the contents	4.17±0.80	9.33	0.00	2.07
Difficulty of the techniques	3.05±0.76	0.40	0.69	0,09
Articulation between content and techniques	4.40±0.70	13.00	0.00	2,83
Suitability of the materials used	4.52±0.80	12.29	0.00	2,69
Effort required	3.40±0.80	3.29	0.00	0,71
Contribution to understand the issues discussed	4.54±0.60	16.52	0.00	3,63
Contribution to reflect critically about the issues discussed	4.31±0.60	14.40	0.00	3,09
Contribution to enhance the curiosity about the issues discussed	4.60±0.67	15.55	0.00	3,38
Satisfaction about the project	4.40±0.67	13.70	0.00	2,96
Evaluation of the project	4.38±0.62	14.37	0.00	3,15

M ± *SD* – Mean ± Standard Deviation. *t* - one sample *t*-test (test value=3) for a 95% confidence interval. *d* - Cohen's *d* measure of effect size. Mean scores rated on a five-point Likert-type scale: 1- Very low/Not at all to 5 - Very high/Completely.

Subchapter 2

Practical work in high school: assessing its effectiveness through an empirical-based analysis

Abstract

Practical activities have long been given a central role in science education. Practical work is widely valued by educators, researchers and policy makers for its potential positive impacts on students' interest and understanding. However, in the last decades, questions have been raised regarding its educational value, aggravated by the scarcity of reliable and robust indicators of its effectiveness. This study provides an empirical-based analysis of the efficacy of practical work, by examining the impact of a practical activity addressing antibiotic resistance and natural antibiotics on high school students' (15 to 17 years old) engagement and their conceptual and procedural skills. Following a case-control mix method approach based on a pre-/post design, data were collected from 147 high school biology students and their teachers. The results demonstrate that practical activities relying in laboratory-based procedures and contextualised in meaningful topics can promote students' engagement and understanding of scientific concepts. But most importantly, they evidence that the educational outcomes fostered by practical work are mediated by a complex network of factors, such as students' personal traits concerning individual interest and learning styles, the instructional design of the activities, and their different degrees of orientation and scaffolding, among others. These findings emphasise the need to critically appraise the effects of practical work and diversify the studies focusing specifically on this topic. The implications of these findings for science education, especially for the design of educational activities, are discussed.

Introduction

Practical work has long been valued as an integral part of science education, distinguishing it from most other school subjects. Educators, researchers and policy makers generally agree that practical activities have the potential for promoting understanding and interest towards science (Abrahams, 2009; Jenkins, 1999; Logar & Savec 2011; Wellington, 1998). Practical work is widely acknowledged by numerous educational frameworks (Abrahams, 2009; Holstermann et al., 2010), and recommended by entities such as the National Association of Biology Teachers (National Association of Biology Teachers [NABT], 2005) or the House of Commons Science and Technology Comittee (House of Commons Science and Technology Committee, 2002). Nevertheless, its effectiveness is far from being consensually accepted. In the last decades and across many countries, the educational worth of practical work has spawned much debate (Gott & Duggan, 2007; Ottander & Grelsson, 2006), sustained by the scarcity of reliable and consistent indicators of the benefits that ensue from conducting this sort of activities (Gott & Duggan, 2007; Logar & Savec, 2011). Therefore, as emphasised by several researchers (Hofstein & Lunetta, 2003; Holstermann et al., 2010; Toplis, 2011), it is necessary to broaden the range of studies on this topic. As argued by Abrahams & Millar (2008), given the wide scope of existing practical activities, assessing the effectiveness of practical work in general would be unreasonable. Instead, it is necessary to focus on specific examples of practical work (Abrahams & Millar, 2008; Holstermann et al., 2010). The present study contributes to bridge this gap by providing an empirical-based analysis of the effectiveness of a laboratory activity focused on a topic with renewed importance - antibiotic resistance and natural antibiotics- on high school biology students' engagement, conceptual understanding, and procedural skills.

Background

The term 'practical work' broadly designates a diversity of activities, with different goals and designs that imply the observation and/or handling of objects and materials (Holstermann et al., 2010; Millar et al., 1999). Practical work is a student-centred teaching/learning strategy that empowers the students by demanding their active participation in the construction of their own knowledge, thus distinguishing itself from teacher-centred approaches (Hofstein & Kind, 2011). For the purpose of this study, practical work is understood as those activities in which the student is actively engaged in the manipulation of objects and materials (Abrahams, 2011; Abrahams & Millar, 2008; Holstermann et al., 2010; Toplis, 2011).

The role of practical work in school science instruction has been characterised by many authors (Hofstein & Lunetta, 2003; Toplis, 2011). According to Abrahams (2011), there are five main purposes for the development of practical activities: enhance learning of scientific concepts and processes; develop laboratory skills; develop habits such as open-mindedness and objectivity; develop scientific reasoning skills and understanding of the nature of science; stimulate interest and enjoyment about science (Abrahams, 2011). Practical work is regarded as a privileged strategy to assist students in making the connection between the observable domain of objects and the abstract domain of ideas and concepts (Abrahams, 2011; Rudduck & McIntyre, 2007; Wellington, 2005). It is also believed that experiencing the investigative character of science through practical work motivates students, mediates the application of knowledge into real situations, and scaffolds the development of scientific literacy (Hofstein & Lunetta, 2003; Hume & Coll, 2008; Lindahl, 2003; Logar & Savec, 2011; Wellington, 1998).

In spite of the widespread belief that increasing the amount of practical work would lead to improved science education, in recent years educators and researchers have raised questions concerning its effectiveness (Abrahams, 2009; Abrahams & Millar, 2008; Millar, 1998; Osborne, 1998; Psillos & Niedderer, 1999; Wellington, 1998). In fact, while the emphasis on practical work increases, there are still seldom reports of the formal assessment of its classroom implementation, and impact on the targeted populations (Gott & Duggan, 2007; Toplis, 2011). Furthermore, the ones that have been made available point towards a complex and fragmented scenario of conflicting findings. Whereas some studies have supported the positive impact of practical work on students' cognitive achievement and interest (Randler & Hulde, 2007; Taraban et al., 2007), others reveal that this is not always the case (Abrahams & Millar, 2008; Holstermann et al., 2010; Logar & Savec, 2011). Practical activities do not warrant improved conceptual achievements when compared to more traditional approaches, such as lectures or demonstrations (Logar & Savec, 2011), nor do they imply the development of high order thinking skills and scientific reasoning (Abrahams & Millar, 2008; Hofstein & Lunetta, 2003). The key issue appears to be breadth of elements underpinning what is envisioned as practical work and the association between goals and practices (Bennett, 2003; Hofstein & Lunetta, 2003; Millar, 1998). For instance, (Abrahams & Saglam, 2010) have noticed that, at least in the United Kingdom, teachers' views and objectives concerning practical work have remained generally unaltered in the last four decades. This is very important, considering that teachers' intentions and behaviours necessarily influence their students' perceptions, performance and achievements (Hofstein & Lunetta, 2003; Ottander & Grelsson, 2006). Furthermore, different activities place different demands on both teachers and students, including the time and resources required, the more or less active student participation, and the degree of inquiry considered (Gott & Duggan, 2007; Holstermann et al., 2010; Millar et al., 1999). This ultimately determines the success of the teaching-learning process. For instance, practical activities relying on stricter, more oriented forms of inquiry may only enable focused learning of contents or techniques, as opposed to the creative and critical learning fostered by authentic scientific inquiry (Hume & Coll, 2008). In addition, specific practical activities may impact either positively or negatively on students' interest and engagement, depending on the type of tasks proposed and on the students' features (Holstermann et al., 2010). Furthermore, the students' apparent interest and active involvement in a given practical task, do not imply cognitive involvement, or enhanced learning (Abrahams, 2009). Hence, it is not safe to assume that practical work is necessarily a beneficial teaching/ learning strategy (Toplis, 2011). Conversely, it is necessary firstly, to reappraise the role of practical work in school science (Wellington, 1998), and secondly, to carry out a deeper examination of the assumptions underlying the expected learning outcomes of practical work, to understand its value and limitations (Osborne, 1998). Given that practical work often represents a considerable investment in terms of time, effort and resources (Abrahams & Saglam, 2010; Bennett, 2003), it becomes essential to understand what can be defined as the goals of practical work in science education and, most importantly, how those goals can be achieved. The answer to this question relies on a sounder, more realistic understanding of the effectiveness of practical work in specific, differentiated contexts (Abrahams & Millar, 2008; Holstermann et al., 2010; Toplis, 2011).

Purpose

Having in mind the issues introduced in the previous section, this study assesses the effects of a practical activity addressing antibiotic resistance and natural antibiotics on the engagement, understanding and procedural skills of Portuguese high school biology students' (15-17 years old), through the use of a case-control mix method approach. The purpose of this investigation was to inform the debate on the effectiveness of practical work, by focusing on specific outcomes and integrating qualitative and quantitative data. The main research questions formulated were:

1. Are there significant changes in students' understanding following their participation in a practical activity?
2. How does the participation in a practical activity influence students' procedural skills?
3. How do students engage in practical work?
4. How is the experience of practical work perceived by students and their teachers?

Research design and Methodology

Most of the studies focusing on the effectiveness of practical work have relied on large-scale questionnaires and interviews and did not compare the respondents' self-reported views with field observations of practice (Abrahams, 2009; Abrahams & Millar, 2008; Toplis, 2011). As admonished by several authors (Cohen et al., 2007; Oppenheim, 1992), looking solely at survey data tends to create a picture of rhetoric nature rather than provide an insightful depiction of real practice. Conversely, integrating both dimensions can strengthen the findings, by enhancing their relevance and generalizability to other settings (Plowright, 2011). Therefore, to address the aforementioned research questions, a longitudinal case-control study following a mix method approach based on a quasi-experimental pre-/post design was set up.

Considering that the activity implemented addressed curriculum-derived contents, it was necessary to account for the expected progression in students' knowledge and performance resulting from their engagement in regular classes. Therefore, to distinguish between these effects, a group of students who did not participate in the activity was used as a no-treatment control (Gravetter & Forzano, 2009; Oppenheim, 1992) – control group I. Furthermore, it was necessary to assess the efficacy of using an instructional design based on practical work and its influence on students' learning achievements. Accordingly, to trace the effects of the activity to the practical tasks, and distinguish those effects from the impact of the accompanying theoretical component, another control group was introduced – control group II. Students in this group were subjected to an intervention consisting in a lecture in which the teacher explored the theory underlying the activity, using the introductory presentation and general discussion topics included in the activity.

Participants

The study involved 147 high school students (aged *M*=17.11, *SD*=0.71 years) in seven 12th grade biology classes from four schools located in Porto, Portugal (three public and one private school), and their teachers. As outlined in Fig. VI.3, the students were organised in an experimental group (four classes; *n*=100, 42 males and 58 females), a control group – I (two classes; *n*=29, 9 males and 20 females), and another control group – II (one class; *n*=18, 9 males and 9 females). Students attending 12th grade biology were considered eligible to participate in the study since, according to the Portuguese biology curricula, the concept of antibiotics is addressed at this instructional level (DGIDC, 2004). This was required to assure the curricular contextualisation of the activity. The participants' recruitment was carried out by randomly selecting a set of schools that had 12th grade biology classes for the 2010/2011 school year, from a list of schools that had collaborated with the researchers in previous studies (Fonseca, Costa, Lencastre, & Tavares, 2011, 2012). Six biology teachers (Figure VI.3) from four schools were invited to take part in the study. Permission for the study was obtained from each school's direction board. The students were informed about the aims of the study, their anonymity was assured, and they were given the option of their data not being used for the purpose of research.

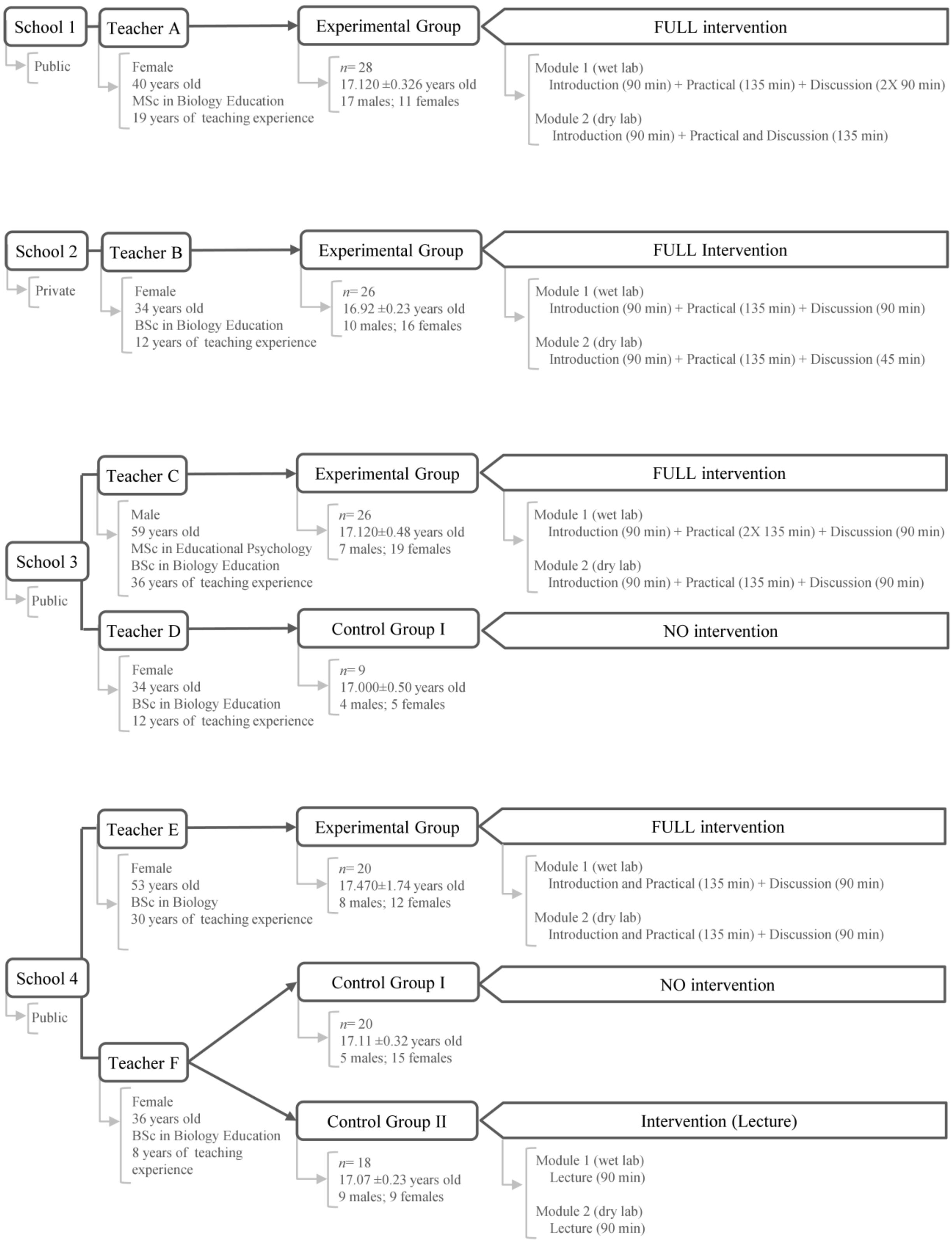


Fig. VI.3. Sample structure and description.

Design, description and implementation of the activity

Drawing on the insights made available by previous studies suggesting the need for engaging activities addressing meaningful topics, but requiring few resources and short preparation time (Fonseca et al., 2012; Hofstein & Lunetta, 2003; Kidman, 2008; Steele & Aubusson, 2004), the activity was envisioned to conform to the following criteria:

- Curricular framing – the contents addressed were framed within the students' curriculum (DGIDC, 2004);
- Meaningfulness – bacterial resistance to antibiotic drugs and antibiotic production are relevant issues from social, cultural and environmental perspectives (Lawson, 2008);
- Authenticity – the procedures selected allow acquainting students with practices carried out in research laboratories (Sadler, 2009);
- Intelligibility and simplicity – the contents and techniques were relatively straightforward for students who were inexperienced in laboratory work;
- Cost effectiveness – the materials required were inexpensive and easily available, dismissing the need for specialised laboratory settings;
- Time effectiveness – the time to prepare and implement the activity was reduced to the minimum required to successfully promote students' learning;
- Safety – all the procedures respected basic laboratory and biosafety rules.

The activity addressed three main instructional aims: i) promote learning of curricular-derived biology topics related with the concept of antibiotics and antibiotic production; ii) familiarise students with the pressing public health issue that is antibiotic resistance; and iii) foster the development of laboratory skills.

The activity combined a wet lab module focused on the testing of natural antibiotics, and an in silico lab module. The first module was an adaptation of a practical activity on the antibiotic properties of phytoactive compounds found in garlic aqueous extract (Fonseca & Tavares, 2011). The second module was a bioinformatics exercise that looked into the evolution of a gene coding for an antibiotic resistance. Gene sequences were retrieved from the National Center for Biotechnology Information (NCBI) database, and the phylogenetic analyses were carried out using the BLAST online tool (Altschul, Gish, Miller, Myers, & Lipman, 1990); and MEGA 5.0 software (Tamura et al., 2011).

From October to December 2010, meetings with the teachers were arranged to decide the activity's implementation schedule. For the experimental group, each module was overall structured upon an introductory session, followed by one practical session, and a group discussion session (Fig. VI.3). For control group I, two discussion classes, one per module, were organised. The lessons were enacted and scaffolded by the teachers, with the researchers taking the role of observers. Each module lasted approximately one week, interspaced by two to four weeks. Since the success of any activity depends on the teachers' adaptation of instructional materials according to the specificities of their students (Fogleman, McNeill, & Krajcik, 2011; Forbes & Davis, 2010), teachers were invited to revise the materials they were provided, without introducing extensive changes, to avoid bias and assure comparisons.

Data collection

From February to June 2011, qualitative and quantitative data were gathered through open and closed questionnaires, classroom observations, artifact analysis, and interviews.

A 17-item survey was developed and used as a pre-/post-test to assess variations in the students' understandings and perceptions about antibiotics and antibiotic resistance (Table VI.3). The questions were developed considering items available in published studies on public perceptions about antibiotic use and antibiotic resistance (Buke et al., 2005; Cebotarenco & Bush, 2008; Davey, Pagliari, & Hayes, 2002; Grigoryan et al., 2007; McNulty, Boyle, Nichols, Clappison, & Davey, 2007a, 2007b). The survey included questions directly aligned with the contents covered in the activity, and tackling more general topics, to assess whether or not the students' participation sparked additional interest on the issues discussed and motivated a further search for information and enhanced knowledge (Abrahams, 2009; NRC, 1996).

A self-reported questionnaire with 21 closed and four semi-open questions was used to gather feedback about the students' experience, namely its interest, difficulty, significance and usefulness. This questionnaire is available from the authors upon request.

Moreover, the students' behavior throughout the activity, particularly concerning their engagement, reasoning and difficulties, were monitored through naturalistic observations (Goodwin, 2009).

The experimental group students were asked to prepare a protocol proposal for module 1, laboratory reports, and classroom presentations. The analysis of the protocol proposals, which were written down after the introduction and prior to the lab classes, allowed understanding how the students envisioned the application of the contents presented to them into an experimental setup (Hofstein & Lunetta, 2003; Toplis, 2011). The students' reports and classroom presentations were examined to evaluate the students' ability to interpret and explain the main findings, discuss their implications, and suggest alternatives to address eventual drawbacks.

Exploratory semi-structured interviews (Oppenheim, 1992) were conducted to gather further details about the teachers' and students' opinions on the activity. These 10-20 min interviews were audio-recorded. Individually, the teachers in the experimental group and control group I were asked to evaluate the activity and supporting resources according to elements ranging from the difficulty of the tasks proposed to the thoroughness and pertinence of the contents. They were instructed to reply considering each element's impact on themselves and on their students. Pairs of students within each class of the experimental group and control group I were selected randomly, and enquired about their perceptions on the work carried out, the quality of the activity, and their participation. The interview scripts are available from the authors upon request.

Table VI.3
Pre-/ post-test used in the study.

Open questions:

Q1. What is an antibiotic and how does it work?
Q2. What traits are desirable in an antibiotic compound?
Q3. Which are the procedures involved in the production of antibiotic drugs?
Q4. What is the meaning of antibiotic resistance?
Q5.[I] List the main measures that can be used to avoid or reduce antibiotic resistance.

True or False questions

Q6. Antibiotics act on bacteria, fungus and virus. (T/F/DK)
Q7. The antibiotic compounds that we use only eliminate pathogenic agents (T/F/DK)
Q8. The antibiotic compounds that we use may be toxic for our own cells (F/F/DK)
Q9. The antibiotic compounds that we used are produced artificially in laboratories (T/F/DK)
Q10.[I] Antibiotics are used specifically to relieve pain (T/F/DK)
Q11.[I] Antibiotics are used specifically to relieve fever (T/F/DK)
Q12.[I] Antibiotics are used specifically to treat cold and flu (T/F/DK)
Q13. There must be cell division for antibiotic resistance to be transferred between bacteria (T/F/DK)

Likert-type scales questions

Q14. Nowadays, it is safe to admit that bacterial infectious diseases are under control (1-totally disagree to 5 - totally agree)
Q15.[I] It is adequate to use an antibiotic without prescription when… (1-totally disagree to 5 - totally agree): a) …we do not have time to go to the doctor; b) …we are in vacation in another country; c) … the appointment is too expensive; d) …we already know the antibiotic because we have used it before; e) …our friends are used to using it and it works for them; f) …we ask for the pharmacist's advice.
Q16.[I] When we are sick (for instance with flu), it is adequate to use an antibiotic to prevent other, more serious diseases (1-totally disagree to 5 - totally agree) I
Q17.[I] The length of treatment with antibiotics must be… (1-totally disagree to 5-totally agree): a) …until the package is finished; b) …until the symptoms disappear; c) …compatible with the physician's instructions.

I – indicates questions addressing contents indirectly covered in the activity.

Data analyses

The data gathered were recorded, codified and categorised. Content analysis of the students' responses to open questions and the transcripts from students' and teachers' interviews was performed according to the guidelines conveyed in Krippendorff (2004) and Weber (1990).

The pre- and post-test data were examined for quantitative and qualitative evidence of the effectiveness of the activity, by evaluating its impact (number of students conveying correct and incorrect notions per response) and variations in the quality of students' reasoning and beliefs (changes in the content of students' responses). For each question, pre- and post-test frequencies of correct and incorrect notions were determined, and coding rubrics were developed based on the relative proportion of such notions and informed by Bloom's taxonomy of cognitive domains (Lord & Baviskar, 2007; Moore & Stanley, 2009; Weil & Kincheloe, 2004) (*Supporting information - Table VI.S5*). The interpretation of the participants' responses followed the recommendations found in Crowe et al. (2008) and Lord & Baviskar (2007).

The students' responses were scrutinised and compared through descriptive and inferential statistical analyses, using IBM SPSS Statistics 20. One sample *t*-tests were used to analyse the responses to the five-point Likert-type items. Mean scores below, equal, or above the midpoint of the scale (test value=3), were considered indicative of negative, neutral or positive positioning, respectively. For the open-ended questions, pre-/post-test variations in the number of correct/incorrect notions and in the scoring rubric scores were compared using paired samples *t*-tests. Cohen's *d* was used to measure the strength of the mean differences observed (Cohen, 1988), with effect sizes equal to 0.20, between 0.50 and 0.80, or above 0.80 being considered small, medium or large, respectively (Cohen, 1988; Gravetter & Forzano, 2009). One-way ANOVA was used to compare the mean responses provided by the students in the experimental, control I and control II groups. Pre-/post-test changes in the responses codified as dichotomous variables (e.g. 'No answer') were examined using the McNemar test (Hill & Lewicki, 2006).

Results

Pre- and post-test performance

Understanding about antibiotics and antibiotic resistance. For the experimental group, pre-/post-test improvements were identified in the rubric scores of the knowledge and understanding questions (Tables VI.4 and VI.5). There were significant increases in the number of students conveying correct notions in questions Q1, Q2, Q6, Q7, Q8, Q3, Q9, Q 4 and Q13 (Table VI.6), and in the amount of correct notions provided per response to those questions (Tables VI.4 and VI.5). There were also significant decreases in the number of students who did not answer questions Q3 (90 vs. 49, $\chi^2(1)=35.56$, $p=0.00$), Q4 (23 vs. 12, $\chi^2(1)=4.00$, $p=0.04$ and Q9 (69 vs. 48, $\chi^2(1)=8.16$, $p=0.00$, and in the amount of incorrect notions mentioned in the responses to questions Q1, Q4 and Q13 (Tables VI.4 and VI.5).

Table VI.4
Pre-/post-test variations in the quality of students' responses to open questions addressing understanding of antibiotic production and resistance.

			Experimental group					Control group I					Control group II					ANOVA	
			M	*SD*	*t*(99)	*p*	*d*	*M*	*SD*	*t*(28)	*p*	*d*	*M*	*SD*	*t*(17)	*p*	*d*	*F*(2,144)	*p*
Q1	Correct notions	Pre-test	0.59	0.81	7.34	0.00	0.95	0.93	0.92	0.41	0.68	0.10	0.72	1.13	2.18	0.04	0.51	1.75	0.18
		Post-test	1.83	1.65				1.03	1.18				1.50	1.86				2.86	0.06
	Incorrect notions	Pre-test	1.04^{a}	0.93	-2.41	0.02	0.30	1.00^{b}	0.93	0.61	0.55	0.16	$0.72^{a,b}$	0.57	1.72	0.10	0.61	3.52	0.03
		Post-test	0.79	0.73				1.14	0.83				1.17	0.86				0.63	0.39
	Rubric score	Pre-test	0.30	0.66	7.37	0.00	0.94	0.41	0.78	1.05	0.30	0.24	0.39	1.04	1.46	0.16	0.32	0.33	0.72
		Post-test	1.42^{a}	1.55				0.66^{b}	1.17				$0.83^{a,b}$	1.65				3.55	0.03
Q2	Correct notions	Pre-test	0.55^{a}	0.78	7.34	0.00	0.83	1.03^{b}	0.91	1.58	0.13	0.39	$0.72^{a,b}$	1.02	3.07	0.01	0.77	3.79	0.03
		Post-test	1.45	1.33				1.41	1.02				1.56	1.15				0.07	0.93
	Incorrect notions	Pre-test	0.02	0.14	0.45	0.66	0.06	0.03	0.19	1.98	0.06	0.54	0.06	0.24	1.00	0.33	0.19	0.39	0.68
		Post-test	0.03^{b}	0.17				0.21^{a}	0.41				$0.11^{a,b}$	0.32				5.57	0.01
	Rubric score	Pre-test	0.53^{b}	0.78	7.39	0.00	0.83	1.00^{a}	0.89	0.89	0.38	0.23	$0.72^{a,b}$	1.02	2.96	0.01	0.53	3.64	0.03
		Post-test	1.44	1.33				1.24	1.15				1.50	1.15				0.33	0.72
Q3	Correct notions	Pre-test	0.12^{a}	0.41	6.91	0.00	1.31	0.48^{b}	0.99	0.66	0.51	0.14	0.72^{b}	1.27	4.41	0.00	0.77	7.30	0.00
		Post-test	1.30^{a}	1.67				0.62^{b}	1.05				2.06^{a}	2.10				4.43	0.01
	Incorrect notions	Pre-test	0.01	0.10	1.00	0.32	0.14	0.00	0.00	-	-	-	0.00	0.00	-	-	-	0.23	0.79
		Post-test	0.00	0.00				0.00	0.00				0.00	0.00				-	-
	Rubric score	Pre-test	0.12^{b}	0.41	7.08	0.00	1.00	0.48^{a}	0.99	0.66	0.51	0.14	0.72^{a}	1.27	4.41	0.00	0.77	7.30	0.00
		Post-test	1.28^{a}	1.60				0.62^{b}	1.05				2.06^{a}	2.10				4.43	0.01
Q4	Correct notions	Pre-test	1.49	1.28	5.21	0.00	0.64	1.14	1.13	1.44	0.16	0.34	1.78	1.56	1.28	0.22	0.32	2.67	0.07
		Post-test	2.35	1.39				1.55	1.30				2.28	1.53				2.80	0.06
	Incorrect notions	Pre-test	0.63^{b}	0.69	-2.00	0.05	0.25	1.07^{a}	0.92	-2.74	0.01	0.60	$0.67^{a,b}$	0.59	-2.05	0.06	0.46	4.10	0.02
		Post-test	0.47	0.58				0.59	0.68				0.39	0.61				0.67	0.51
	Rubric score	Pre-test	1.02	1.09	5.52	0.00	0.73	0.69	0.89	1.79	0.08	0.45	1.11	1.08	1.79	0.08	0.71	1.30	0.28
		Post-test	1.98^{a}	1.51				1.14^{b}	1.09				2.11^{a}	1.68				4.12	0.02

M – Mean. *SD* – Standard Deviation. *d* – Cohen's *d* measure of effect size. Pre-test and post-test mean scores compared using paired samples *t*-tests (confidence interval of 95%). Differences between groups in the pre-test and post-test assessed using ANOVA: a,b – different letters indicate significant differences, for a 95% confidence interval. A full description of the questions is available in Table VI.3.

Table VI.5

Pre-/post-test variations in the quality of students' justifications to True or False questions addressing understanding of antibiotic production and resistance.

			Experimental group					Control group I					Control group II					ANOVA	
			M	*SD*	*t*(99)	*p*	*d*	*M*	*SD*	*t*(28)	*p*	*d*	*M*	*SD*	*t*(17)	*p*	*d*	*F*(2,144)	*p*
Q6	Correct	Pre-test	0.09	0.29	-4.34	0.00	0.43	0.14	0.35	0.33	0.75	0.09	0.06	0.24	2.56	0.02	0.73	0.48	0.62
	notions	Post-test	0.25	0.44				0.17	0.38				0.33	0.49				0.79	0.46
	Incorrect	Pre-test	0.29	0.46	-0.87	0.39	0.11	0.21	0.49	-0.63	0.54	0.16	0.22	0.43	-1.37	0.19	0.48	0.46	0.63
	notions	Post-test	0.24	0.49				0.14	0.35				0.06	0.24				1.63	0.20
	Rubric	Pre-test	0.17	0.55	4.62	0.00	0.49	0.28	0.70	0.68	0.50	0.19	0.11	0.47	1.72	0.10	0.61	0.54	0.58
	score	Post-test	0.52	0.86				0.41	0.78				0.56	0.92				0.21	0.81
Q7	Correct	Pre-test	0.15^{b}	0.46	5.53	0.00	0.72	0.10^{b}	0.31	0.37	0.71	0.11	0.67^{a}	1.03	-1.37	0.19	0.17	7.71	0.00
	notions	Post-test	0.68^{a}	0.94				0.14^{b}	0.35				$0.50^{a,b}$	0.92				4.54	0.01
	Incorrect	Pre-test	0.02	0.14	1.14	0.26	0.16	0.07	0.26	1.44	0.16	0.38	0.00	0.00	-	-	-	1.30	0.28
	notions	Post-test	0.05	0.22				0.00	0.00				0.00	0.00				1.21	0.30
	Rubric	Pre-test	0.36^{b}	0.79	5.82	0.00	0.75	0.31^{b}	0.66	1.56	0.13	0.45	1.06^{a}	1.47	-1.29	0.22	0.16	5.19	0.01
	score	Post-test	1.18	1.34				0.62	0.73				0.83	1.34				2.51	0.09
Q8	Correct	Pre-test	0.20	0.45	3.80	0.00	0.45	0.24	0.44	0.00	1.00	0.00	0.22	0.43	0.37	0.72	0.13	0.10	0.90
	notions	Post-test	0.42	0.52				0.24	0.44				0.28	0.46				1.80	0.17
	Incorrect	Pre-test	0.01	0.10	0.00	1.00	0.00	0.03	0.19	1.00	0.33	0.26	0.00	0.00	-	-	-	0.64	0.53
	notions	Post-test	0.01	0.10				0.00	0.00				0.00	0.00				0.23	0.79
	Rubric	Pre-test	0.24	0.55	4.14	0.00	0.51	0.31	0.47	0.00	1.00	0.00	0.28	0.46	0.62	0.54	0.19	0.21	0.81
	score	Post-test	0.55	0.66				0.31	0.54				0.39	0.70				1.79	0.17
Q9	Correct	Pre-test	0.13	0.34	6.16	0.00	0.83	0.24	0.51	-0.30	0.77	0.07	0.22	0.43	2.05	0.06	0.48	1.16	0.32
	notions	Post-test	0.58^{a}	0.68				0.21^{b}	0.49				$0.50^{a,b}$	0.71				3.66	0.03
	Incorrect	Pre-test	0.00	0.00	-	-	-	0.00	0.00	1.00	0.33	0.26	0.00	0.00	-	-	-	-	-
	notions	Post-test	0.00	0.00				0.03	0.19				0.00	0.00				2.06	0.13
	Rubric	Pre-test	0.19	0.49	6.80	0.00	0.30	0.41	0.82	0.19	0.85	0.04	0.39	0.70	0.98	17.00	0.06	2.09	0.13
	score	Post-test	0.93	1.05				0.45	0.69				0.94	1.21				2.68	0.07
Q10^{I}	Correct	Pre-test	0.19	0.42	1.69	0.09	0.20	0.10	0.31	1.68	0.10	0.37	0.22	0.43	0.57	0.58	0.11	0.64	0.52
	notions	Post-test	0.28	0.47				0.24	0.44				0.28	0.57				0.07	0.93
	Incorrect	Pre-test	0.02	0.14	0.58	0.57	0.06	0.00	0.00	-	-	-	0.06	0.24	-1.00	0.33	0.34	0.85	0.43
	notions	Post-test	0.03	0.17				0.00	0.00				0.00	0.00				0.71	0.49
	Rubric	Pre-test	0.69	0.72	3.04	0.00	0.33	0.69	0.66	0.00	1.00	0.00	0.61	0.70	3.43	0.00	0.38	0.10	0.91
	score	Post-test	0.94	0.79				0.69	0.66				1.11	0.76				1.92	0.45
Q11^{I}	Correct	Pre-test	0.12	0.33	1.15	0.25	0.14	0.10	0.31	1.00	0.33	0.27	0.22	0.43	1.00	0.33	0.24	0.81	0.45
	notions	Post-test	0.17^{a}	0.40				0.03^{b}	0.19				$0.33^{a,b}$	0.49				0.44	0.04
	Incorrect	Pre-test	0.07	0.26	-0.58	0.57	0.08	0.00	0.00	-	-	-	0.00	0.00	-	-	-	1.73	0.18
	notions	Post-test	0.05	0.22				0.00	0.00				0.00	0.00				1.21	0.30
	Rubric	Pre-test	0.41	0.60	3.69	0.00	0.39	0.41	0.63	-2.27	0.03	0.39	0.50	0.79	1.43	0.17	0.33	0.16	0.86
	score	Post-test	0.67^{a}	0.71				0.21^{b}	0.41				0.78^{a}	0.88				5.86	0.00
Q12^{I}	Correct	Pre-test	0.07	0.26	0.28	0.78	0.04	0.00	0.00	1.00	0.33	0.26	0.06	0.24	1.46	0.16	0.35	1.06	0.35
	notions	Post-test	0.08	0.31				0.03	0.19				0.17	0.38				1.094	0.34
	Incorrect	Pre-test	0.13	0.34	0.45	99.00	1.00	0.00	0.00	-	-	-	0.11	0.32	0.42	17.00	0.58	1.05	0.352
	notions	Post-test	0.13	0.34				0.00	0.00				0.06	0.24				1.36	0.26
	Rubric	Pre-test	0.30	0.56	2.20	0.03	0.25	0.34	0.48	0.83	0.41	0.21	0.33	0.49	2.92	0.01	0.62	0.09	0.91
	score	Post-test	0.44	0.58				0.45	0.51				0.67	0.59				1.26	0.29
Q13	Correct	Pre-test	0.09	0.29	5.76	0.00	0.76	0.07	0.26	0.00	1.00	0.00	0.17	0.51	2.20	0.04	0.72	0.57	0.57
	notions	Post-test	0.50^{a}	0.70				0.07^{b}	0.26				0.61^{a}	0.70				5.97	0.00
	Incorrect	Pre-test	0.18	0.41	-1.99	0.05	0.24	0.24	0.44	-1.00	0.33	0.17	0.06	0.24	-1.00	0.33	0.34	1.21	0.30
	notions	Post-test	0.09	0.32				0.17	0.38				0.00	0.00				1.70	0.19
	Rubric	Pre-test	0.18	0.48	7.22	0.00	0.88	0.07	0.26	-1.44	0.16	0.38	0.28	0.75	3.61	0.00	0.99	1.62	0.20
	score	Post-test	0.93^{a}	1.11				0.00^{b}	0.00				1.22^{a}	1.11				11.74	0.00

M – Mean. *SD* – Standard Deviation. *d* – Cohen's *d* measure of effect size. Pre-test and post-test mean scores compared using paired samples *t*-tests (confidence interval of 95%). Differences between groups in the pre-test and post-test assessed using ANOVA: a,b – different letters indicate significant differences, for a 95% confidence interval. I – indicates questions addressing contents indirectly covered in the activity. A full description of the questions is available in Table VI.3.

For control group II, there were some improvements, reflected by the increases in: the average number of correct notions included in the responses to questions Q1, Q2, Q6, Q3, and Q13; and the higher post-test rubric scores for questions Q3 and Q13 (Tables VI.4 and VI.5). There was also a decrease in the number of students who did not answer question Q3 (13 vs. 6, $\chi^2(1)=5.14$, $p=0.02$).

For control group I, no significant pre-/post-test variations were observed, except for the decrease in the number of incorrect notions in the responses to question Q4 (Tables VI.4 and VI.5).

Perceptions about antibiotic use and the control of infectious diseases. The only significant pre-/post-test difference in the experimental group was observed for question Q15: the students went from being unsure about whether or not it is adequate to take the pharmacist's advice on prescribed antibiotics to the perception that it is not ($M_{pre\text{-}test}=3.45$, $SD=1.15$ vs. $M_{post\text{-}test}=3.08$, $SD=1.24$, $t(99)=-2.85$, $p=0.001$, $d=0.31$). However, the quality of the claims made by these students to support their responses to questions Q5, Q14, Q15 and Q16 improved. There were increases in: the number of students mentioning reasonable notions in response to questions Q5 and Q16 (Table VI.6); the amount of reasonable notions reported in response to questions Q5 and Q14 (Table VI.7); and in the rubric scores for questions Q5 and Q14 (Table VI.7). There were also decreases in the number of students who did not answer question Q5 (32 vs. 9, $\chi^2(1)=16.69$, $p=0.00$), and in the number of unreasonable notions conveyed in response to question Q15 (Table IV.7).

For control group II, there were no significant changes in the students' perceptions about antibiotics ($p>0.05$). The justifications presented by these students in response to questions Q5, Q14 and Q16 improved: the amount of reasonable notions increased and the rubric scores were enhanced (Table VI.7). There was also a decrease in the number of students who did not answer question 16 (17 vs. 8, $\chi^2(1)=7.11$, $p=0.00$).

For control group I, the students' perceptions and justifications did not change from pre- to post-test ($p>0.05$; Table VI.7).

Table VI.6
Correct and incorrect notions provided in the pre-test and in the post-test.

			EXPERIMENTAL GROUP				**CONTROL GROUP I**				**CONTROL GROUP II**			
			n		**McNemar**		***n***		**McNemar**		***n***		**McNemar**	
		Notion	Pre-test	Post-test	$\chi^2(1)$	p	Pre-test	Post-test	$\chi^2(1)$	p	Pre-test	Post-test	$\chi^2(1)$	p
Q1	Correct	Medicines	30	8	14.70	0.00	10	5	1.78	0.18	3	8	2.29	0.13
		Chemical compounds	5	17	7.56	0.00	5	6	0.00	1.00	2	2	0.00	1.00
		Natural compounds	0	16	14.06	0.00	1	1	0.00	1.00	0	1	0.00	1.00
		Synthetic compounds	1	9	6.13	0.01	1	2	0.00	1.00	0	0	-	-
		Act on bacteria	12	42	24.74	0.00	4	6	0.17	0.69	3	6	0.57	0.45
		Kill	3	36	27.68	0.00	2	0	0.50	0.50	2	2	0.00	1.00
		Prevent reproduction	2	28	22.32	0.00	1	0	0.00	1.00	1	2	0.00	1.00
	Incorrect	Act specifically on pathogens	30	25	0.52	0.47	11	10	0.00	1.00	1	8	5.14	0.02
		Contain antibodies	6	0	4.17	0.03	2	0	0.50	0.50	1	1	0.00	1.00
Q2	Correct	Low cost	1	10	7.11	0.00	0	0	-	-	1	1	0.00	1.00
		Act rapidly	3	7	1.50	0.22	6	15	5.82	0.01	0	2	0.50	0.50
		Broad spectrum	0	23	21.04	0.00	0	0	-	-	0	3	1.33	0.25
		Narrow spectrum	0	10	8.10	0.00	0	2	0.50	0.50	2	5	0.80	0.38
		Easy to use	0	9	7.11	0.00	0	1	0.00	1.00	0	1	0.00	1.00
Q3	Correct	Search for compounds with antimicrobial	1	14	9.60	0.00	2	3	0.00	1.00	1	5	1.50	0.22
		Isolate the antibiotic compound	2	22	15.04	0.00	1	2	0.00	1.00	1	5	2.25	0.13
		Conduct tests	2	27	21.33	0.00	6	6	0.00	1.00	2	5	0.80	0.38
		Conduct microbiological tests	0	10	8.10	0.00	0	0	-	-	1	3	0.50	0.50
		Conduct clinical trials	0	6	4.17	0.03	0	0	-	-	3	4	0.00	1.00
		Formulation/ production	2	27	23.04	0.00	0	2	0.50	0.50	0	3	1.33	0.25
		Concentration	0	11	9.09	0.00	1	1	0.00	1.00	0	1	0.00	1.00
Q4	Correct	Feature of the bacterium	50	74	13.92	0.00	11	12	0.00	1.00	11	12	0.00	1.00
		Bacteria are immune to the antibiotic	44	69	12.26	0.00	7	10	0.44	0.51	8	9	0.00	1.00
		Bacteria adapt	13	37	13.92	0.00	3	6	0.80	0.38	5	10	2.29	0.13
	Incorrect	Feature of the host	16	5	5.88	0.01	12	6	3.13	0.07	2	2	0.00	1.00
Q5	Correct	Avoid self-medication	12	38	19.53	0.00	4	1	1.33	0.25	1	4	1.33	0.25
		Follow the physician's instructions	6	19	8.47	0.00	0	3	1.33	0.25	1	4	1.33	0.25
		Promote information campaigns	2	9	5.14	0.02	0	0	-	-	0	0	-	-
Q6	Correct	Only act against bacteria	9	25	14.06	0.00	4	5	0.00	1.00	1	6	3.20	0.06
Q7	Correct	Antibiotics eliminate other agents	11	36	18.58	0.00	3	2	0.00	1.00	6	5	0.00	1.00
		Limited selectivity/ specificity	0	9	7.11	0.00	0	1	0.00	1.00	1	1	0.00	1.00
		Antibiotics also eliminate symbiotic/ beneficial bacteria	4	19	9.33	0.00	0	0	-	-	5	3	0.50	0.50
Q9	Correct	Some may exist in nature	4	41	35.21	0.00	5	4	0.00	1.00	4	5	0.00	1.00
		There are natural antibiotics, such as garlic	0	6	4.17	0.03	0	0	-	-	0	2	0.50	0.50
Q13	Correct	Bacteria can transfer plasmids	0	7	5.14	0.02	0	0	-	-	1	1	0.00	1.00
		There can be horizontal gene transfer	0	19	17.05	0.00	0	0	-	-	1	4	1.33	0.25
Q14	Correct	Bacterial resistance is increasing	10	31	12.90	0.00	4	5	0.00	1.00	2	7	2.29	0.13
Q16	Correct	It depends on the doctor	8	22	9.39	0.00	6	4	0.17	0.69	0	1	0.00	1.00

n – number of students. Only the significant pre-/post-test variations (confidence interval of 95%) are displayed. A full description of the questions is available in Table VI.3.

Table VI.7

Pre-/post-test variations in the quality of students' responses to Likert-type scale questions addressing perceptions about antibiotic production and resistance.

			Experimental group					Control group I					Control group II					ANOVA	
			M	*SD*	*t*(99)	*p*	*d*	*M*	*SD*	*t*(28)	*p*	*d*	*M*	*SD*	*t*(17)	*p*	*d*	*F*(2,144)	*p*
Q5	Correct notions	Pre-test	0.80	0.84	8.52	0.00	0.82	0.79	0.73	0.42	0.68	0.09	0.67	0.91	2.96	0.01	0.65	0.20	0.82
		Post-test	1.61^{a}	1.12				0.86^{b}	0.79				$1.44^{a,b}$	1.42				5.15	0.01
	Incorrect notions	Pre-test	0.20	0.43	-0.39	0.70	0.05	0.10	0.31	1.00	0.33	0.20	0.06	0.24	1.00	0.33	0.19	1.49	0.23
		Post-test	0.18	0.39				0.17	0.38				0.11	0.32				0.25	0.78
	Rubric score	Pre-test	0.73	0.83	7.69	0.00	0.78	0.76	0.74	0.21	0.83	0.04	0.67	0.91	2.50	0.02	0.59	0.07	0.93
		Post-test	1.52^{a}	1.17				0.79^{b}	0.77				$1.39^{a,b}$	1.46				4.56	0.01
Q14	Correct notions	Pre-test	0.78	0.71	4.21	0.00	0.41	0.76	0.79	-0.19	0.85	0.05	0.61	0.70	2.36	0.03	0.60	0.42	0.66
		Post-test	1.12	0.95				0.72	0.75				1.00	0.59				2.31	0.10
	Incorrect notions	Pre-test	0.00^{b}	0.00	1.00	0.32	0.14	0.00^{b}	0.00	-	-	-	0.06^{a}	0.24	-1.00	0.33	0.34	3.72	0.03
		Post-test	0.01	0.10				0.00	0.00				0.00	0.00				0.23	0.79
	Rubric score	Pre-test	0.78	0.71	4.17	0.00	0.40	0.76	0.79	-0.19	0.85	0.05	0.61	0.70	2.36	0.03	0.60	0.42	0.66
		Post-test	1.11	0.93				0.724	0.75				1.00	0.59				2.25	0.10
Q15	Correct notions	Pre-test	0.86	0.91	1.02	0.31	0.12	0.66	0.72	-0.21	0.84	0.06	0.61	0.85	1.57	0.14	0.52	1.05	0.35
		Post-test	0.76	0.75				0.62	0.68				1.22	1.44				2.86	0.06
	Incorrect notions	Pre-test	0.11	0.31	-2.81	0.01	0.37	0.14	0.44	-1.68	0.10	0.45	0.00	0.00	1.46	0.16	4.38	1.09	0.34
		Post-test	0.02	0.14				0.00	0.00				1.00	0.32				2.96	0.06
	Rubric score	Pre-test	0.78	0.92	-0.30	0.76	0.04	0.55	0.69	0.44	0.66	0.10	0.61	0.85	1.49	0.16	0.47	0.92	0.40
		Post-test	0.75	0.76				0.62	0.68				1.11	1.23				2.10	0.13
Q16	Correct notions	Pre-test	0.29	0.52	1.94	0.06	0.21	0.34	0.48	0.00	1.00	0.00	0.06	0.24	2.72	0.02	0.95	2.18	0.12
		Post-test	0.40	0.51				0.34	0.55				0.44	0.51				0.22	0.80
	Incorrect notions	Pre-test	0.08	0.27	-2.93	0.00	0.41	0.07	0.26	1.00	0.33	0.18	0.00	0.00	1.00	0.33	0.36	0.76	0.47
		Post-test	0.00	0.00				0.03	0.19				0.06	0.24				2.37	010
	Rubric score	Pre-test	0.29	0.52	1.94	0.06	0.21	0.34	0.48	0.00	1.00	0.00	0.06	0.24	2.72	0.02	0.97	2.18	0.12
		Post-test	0.40	0.51				0.34	0.55				0.44	0.51				0.22	0.80
Q17	Correct notions	Pre-test	0.56	0.66	0.26	0.79	0.03	0.41	0.50	0.00	1.00	0.00	0.33	0.59	1.68	0.11	0.50	1.39	0.25
		Post-test	0.58	0.62				0.41	0.50				0.67	0.77				1.12	0.33
	Incorrect notions	Pre-test	0.00	0.00	1.00	0.32	0.01	0.00	0.00	-	-	-	0.00	0.00	1.00	0.33	0.36	-	-
		Post-test	0.01	1.00				0.00	0.00				0.06	0.24				1.43	0.24
	Rubric score	Pre-test	0.56	0.66	0.26	0.79	0.03	0.41	0.50	0.00	1.00	0.00	0.33	0.59	1.80	0.09	0.54	1.39	0.25
		Post-test	0.58	0.62				0.41	0.50				0.72	0.83				1.43	0.24

M – Mean. *SD* – Standard Deviation. *d* – Cohen's *d* measure of effect size. Pre-test and post-test mean scores compared using paired samples *t*-tests (confidence interval of 95%). Differences between groups in the pre-test and post-test assessed using ANOVA: a,b – different letters indicate significant differences, for a 95% confidence interval. I – indicates questions addressing contents indirectly covered in the activity. A full description of the questions is available in Table VI.3.

Classroom observations

Introductory classes. The pre-laboratory classes in both modules (Fig. VI.3) were enacted as interactive lectures in which the teachers prompted whole class discussions by using the presentations provided (available from the authors upon request), with (Teachers A, E and F; Fig. VI.3) or without (Teachers B and C, Fig. VI.3) adaptations. The students were engaged in debate, especially in the first module's introduction, taking notes, asking and answering their teachers' and colleagues' questions. They were also eager to share their own experiences in using antibiotics, and appeared to be particularly concerned about the importance of assuring judicious antibiotic use. For the first module, it was also noticed that most students were excited about the chance to propose a protocol to test their hypothesis.

Laboratory classes. The students were focused on their tasks and attentive to their teachers' instructions and to the guidelines in the protocols. When working in groups, they quickly and autonomously mobilised themselves in sorting the materials needed, managing the time to complete each task, and taking notes and photos. They were manifestly eager to "get everything right", and clarified every query by consulting their teacher and colleagues. They were especially concerned about biosafety and how to avoid the contamination of their work. When confronted with the unavailability of some materials and internet connection problems, the students strived to reach solutions, mainly through peer collaboration. They were excited about testing garlic's antibiotic properties and, encouraged by the teachers, some brought into the classroom other plants to test. Nevertheless, some students seemed to be too attached to the protocols, especially in the dry-lab exercises, and also quite worried about the activity reports they had to do. These students tended not to swerve from what they were specifically instructed to do.

Discussion classes. Following the laboratory classes, the teachers mediated the interpretation and discussion of the results. Whereas not all results were conclusive, the students remained engaged and reviewed the steps performed, attempting to identify possible causes for those results. The main element emphasised by the students in these sessions was the significance of the activity's findings within the complexity of antibiotic drug production and the importance of rational antibiotic use.

Student's feedback on the activity

The students enjoyed their experience with the activity and felt that it had corresponded to their expectations (Table VI.8). They considered that the activity was interesting, particularly the wet lab exercises, and that it had sparked their curiosity about the issues discussed, in spite of agreeing that the tasks performed required effort (Table VI.8). They found the contents to be accessible, interesting and well structured, the alternative materials to be suitable and the techniques simple and adequately articulated with the contents (Table VI.8). Furthermore, they believed that their participation had contributed to enhance their understanding about this topic and their ability to critically reflect upon it (Table VI.8). Nevertheless, they were not certain about the usefulness of this activity for their academic pathway or for their daily lives (Table VI.8). Four students reported that they were surprised about garlic's antibiotic properties, and three about the fact that not all outcomes were conclusive. Many students highlighted the opportunity to conduct laboratory work as a major positive aspect of this activity (n=31), and also the new knowledge that it fostered (n=17). As less positive aspects, eight of them mentioned that there were material constraints and five felt that the theory and the bioinformatics exercises were not as exciting as the laboratory practice.

Student artifacts

Protocol proposals. The proposals put forth by the students varied in complexity and structure, some having only text, and others including drawings and schemes. There were students who suggested lists of materials, discussed how the antibiotic compound could be extracted and kept functional, and presented the expected outcomes. The importance of using replicates and controls was emphasised in a few proposals. Many proposed the use of bacteria to test extracts from plants and herbs such as garlic, oregano, rosemary, vanilla, or laurel. While most of these proposals were incomplete, only two incorrect notions were encountered:

the idea that natural antibiotics could be tested on viruses and fungus, and the belief that an antibiotic's effects can be observed using a microscope.

Table VI.8. Students' (*n*=98) feedback on the activity.

	M	*SD*	*t*(96)	*p*	*d*
Difficulty of the contents	2.93	0.65	-1.09	0.25	0.15
Interest of the contents	3.52	0.95	5.36	0.00	0.78
Organisation and structuring of the contents	3.69	0.71	9.55	0.00	1.37
Difficulty of the techniques	2.85	0.71	2.14	0.04	0.30
Articulation between contents and techniques	3.82	0.74	11.03	0.00	1.58
Suitability of the materials used	3.68	0.85	7.79	0.00	1.13
Effort required	3.32	0.65	4.81	0.00	0.69
Contribution to understand the issues discussed	3.59	0.81	7.12	0.00	1.03
Contribution to reflect critically about the issues discussed	3.40	0.93	4.25	0.00	0.61
Satisfaction about the activity	3.74	0.88	8.30	0.00	1.19
Correspondence with expectations	3.47	0.75	6.22	0.00	0.89
Interest of the activity	3.63	0.83	7.43	0.00	1.07
Adequacy of the introductory theory	3.60	0.93	6.32	0.00	0.91
Interest of the wet lab exercises	3.74	0.78	9.36	0.00	1.34
Interest of the dry lab exercises	3.10	1.10	0.81	0.42	0.13
Contribution to enhance the curiosity about the issues discussed	3.27	0.95	2.81	0.01	0.40
Academic/ professional usefulness	2.92	1.13	0.72	0.48	0.10
Personal usefulness	2.86	1.01	1.31	0.19	0.20

M- mean. *SD* - Standard deviation. *t* - one sample *t*-test (test value=3) for a 95% confidence interval. *d* - Cohen's *d* measure of effect size. Mean scores rated on a five-point Likert-type scale: 1- Very low/Not at all… to 5 - Very high/Completely… The full version of the feedback questionnaire is available from the authors upon request.

Reports and Presentations. The format, degree of detail and content of the student reports and presentations were consistent with the guidelines provided by their teachers. The students worked on the aesthetic worth of their work, by creating appealing covers and evocative titles, interweaving the text with figures and documenting the procedures and results with photos. Whereas some of them focused strictly on the discussion of the results obtained, most of them scrutinised the meaningfulness of their findings in the context of the warfare against bacterial infectious disease. They claimed that the activity enlightened them about "how complex it is to produce antibiotics". The discussion sections in the students reports were aligned with the introductory sections and addressed the topics explored in class. A couple of students actually reproduced the contents comprised in the teacher's introduction, that was made available to them, and the sequence in which these were presented. On the contrary, in the presentations, the students were more careful in the way they organised the information to show to their peers. In spite of recurrent reports on "having wrong or no results", the students coped with these situations, by reflecting upon what might have happened, moving from inadequate lab practice, to speculating about unforeseen factors, such as the origin of the garlic cloves used, or the plate incubation periods.

Student and teacher interviews

The students in the experimental group complained about the limited opportunities for laboratory work in their classes and mentioned that they were very excited about this activity. They said that, although structurally identical, this activity was more elaborate and organised than previous ones. They valued the chance to develop their laboratory skills, which they believed to be essential for when they got to the university. Furthermore, they claimed that practical work enabled them to better understand the theory and that it was more enjoyable than traditional classes. Some added that the contents were interesting, since the issues discussed were socially relevant and "truly affect peoples' lives". They thought that this type of contextualisation was necessary for the success of the activity. Likewise, in evaluating the structure of the activity, they highlighted the importance of the starting points given by the introductory class, without which they "would be lost, not knowing what to do, or why to do it". While most of them reported that the length of the activity was adequate, some believed that the laboratory classes should be expanded, stating that "once we begin, we get carried away and want to continue doing more things in the lab". They agreed that the activity was relatively simple, although the bioinformatics exercises were "a bit confusing". They also said that proposing a protocol was hard work, but at the same time enticing, as it demanded their attention and enabled them to make sense of what they were about to do and what they could expect. In control group II, the students confirmed that the presentations used in their classes were identical to what they were used to. Most importantly, they further sustained that practical work is required for them to develop the skills needed for university, that it is not developed as often as it should be, and that a theoretical introduction is not expendable.

The teachers assessed the activity very positively. They considered that it was well-contextualised and structured, and that the supporting materials were useful, informative and thorough. They believed that the format used resembled their own, although they usually did not ask the students to propose protocols. They did not feel particularly uncomfortable about using materials designed by someone else, as long as they could adapt them. They thought that the contents and procedures were not too complex both for themselves and for their students, in spite of some reservations concerning the bioinformatics' module, which they perceived as more demanding. In justifying why they were interested in this activity, they reported that practical work is a way to foster improved understandings by allowing to integrate theory and practice, promoting learning of procedural skills, and increasing student motivation. Nevertheless, they admitted that they did not use it that often, mainly due to time and material limitations. This was another reason why they appreciated an activity based on easily available resources. Furthermore, they agreed that it fostered their students' creativity.

Discussion

Does practical work promote students' understanding?

The assumption that practical work yields improvements in students' understanding of scientific concepts and phenomena is the main reason why this is regarded as such an invaluable learning/teaching strategy, although, paradoxically, it is also a cause of debate about its educational worth (Abrahams & Millar, 2008; Hofstein & Lunetta, 2003). In this study, the qualitative and quantitative indicators gathered demonstrate that practical work can be effective in promoting students' knowledge and understanding. This was evidenced by the quality of the students' reports and presentations, by the variation in their pre-test and post-test performance, and further sustained when comparing their achievements with the achievements of the students who did not participate in the practical activity (control group II).

Since this activity was framed within the students' curriculum (DGIDC, 2004), this suggests that in this particular case, practical work provided a more powerful contribution to the sophistication of students' understandings about the topic than traditional instruction. Overall, this outcome is concurrent with previous studies (Randler & Hulde, 2007; Taraban et al., 2007). However, the picture becomes more complex when the pre-/post-test data from the students who participated in the lecture (control group II) is considered. Although to a lesser extent, these students also experienced improvements in their conceptualisation and reasoning abilities, which might be explained by the deeper exploration of the supporting material by the teacher in this control group. It must be noted that there were no major differences in the starting points of the students from the three groups, according to the ANOVA results. Interestingly, in a recent study, Logar & Savec (2010) verified that more transmissive demonstration-based lectures fostered higher increases in students' content knowledge than hands-on activities. While the present study's findings are not utterly in line with that observation, they evidence the importance of lectures. Nevertheless, the experimental group students generally outperformed their counterparts in both control groups. In control group II, it seems that the lecture was more effective in getting those students who already responded satisfactory in the pre-test to enhance the quality of their responses. A possibility is that these differential effects in the performances of students from both groups are related with their diverse learning styles (Thorne & Mackey, 2007). To unveil the influence of the activity on students' understanding, other issues must be considered, specifically the levels at which this learning occurred and how they relate to the activity itself.

At what levels does practical work influence students' understanding?

Practical work is expected to foster conceptual understanding at various levels, from the knowledge of scientific concepts to the application of that knowledge in everyday life (Hofstein & Lunetta, 2003). Having this in mind, this study assessed variations in students' understanding based on their responses to questions covering contents directly and indirectly addressed in the practical activity and with increasing degrees of complexity and abstraction. It was observed that there were measurable improvements in the experimental group students' understanding of scientific concepts. Consistently with the belief that practical work allows linking the domain of objects with the domain of ideas (Abrahams & Millar, 2008; Millar et al., 1999), these findings suggest that the activity was successful in enabling the students to transition between micro and macro-levels of conceptualisation. This is relevant given that this connection, which can be challenging for students on this instructional level (Tibell & Rundgren, 2010), is necessary to fully grasp the meaning and consequences of antibiotic resistance (Jones & Rua, 2008; Milandri, 2004). Nevertheless, these improvements were more evident for the contents that were specifically addressed in the practical activity and less for those that were tacitly introduced. Thus, it seems that the students' conceptual learning occurred more on a domain-specific level. Likewise, there were no changes in the students' perceptions about antibiotic use, although their participation elicited improvements in the quality of their arguments in this regard. It is possible that this happened because, from the start, these students were aware of how important it is to use antibiotics correctly and acknowledged the main consonant behaviours. To some extent, this assumption is supported by the interview data, as a couple of students admitted that they already knew what to do, but the activity led them to understand why. However, these outcomes can also suggest that the activity had a limited impact on some students' capacity to integrate the conceptual understanding developed and apply it in hypothetical everyday situations.

Taken together, these findings allude to the ideas that students are expected to learn from practical work. In this study, the main reason why the teachers valued practical work in general, and this activity in particular, was the possibility for students to confirm and apply theoretical notions, a view widely shared amongst teachers (Millar et al., 1999; Ottander & Grelsson, 2006). Moreover, consistently with other studies (Cerini et al., 2003; Osborne & Collins, 2000; Toplis, 2011), the students reported that the activity made it easier for them to understand and recall the theory and concepts. While it is possible that these self-reported enhancements in understanding and recollection do not translate in actual scientific learning (Abrahams & Millar, 2008), the students' rapports are backed up by the pre-/post data and by their reports and presentations. Based on all these elements, it appears that the integration of theory and practice was attained. In this case, the students' learning was aligned with their expectations and with their teachers' intentions. However, this does not always happen, and there is frequently a displacement between the intended learning and the learning that actually takes place (Abrahams & Millar, 2008; Hofstein & Lunetta, 2003; Toplis, 2011).

How can students' understanding be prompt through practical work?

The expected outcomes of practical work must be not only aligned with the goals, but also with the types of tasks that students are required to perform and with whether or not those tasks foster a minds-on engagement (Millar, 1998). It has been shown that most of the practical work carried out at high school levels still follows 'recipe-like' exercises that tend to produce content and skill-based learning, rather than the meaningful learning advocated in current syllabuses (Hofstein & Lunetta, 2003; Hume & Coll, 2008; Ottander & Grelsson, 2006; Toplis, 2011). Even though, according to international and national curricular guidelines (DGIDC, 2004; NABT, 2005; NRC, 1996; The House of Commons Science and Technology Committee, 2002), the process of scientific inquiry has been acclaimed as a privileged tool to promote authentic and meaningful learning, inquiry-based activities are seldom incorporated in science classes as teachers have to cope with limitations in resources, inflexible schedules, large-classes and extensive course content, among other constraints (Hofstein & Lunetta, 2003; Ottander & Grelsson, 2006). Taking this into account, the activity developed in this study was presented and enacted as a guided-inquiry activity (Eisenkraft & Anthes-Washburn, 2008; Maniotes et al., 2007), which the participants perceived as an efficient way to balance learning and time-effectiveness. Usually, in traditional 'recipe-like' practical work, students follow pre-set instructions and are not involved in the planning of the activities (Hofstein & Lunetta, 2003; Ottander & Grelsson, 2006), which may hinder their understanding, namely by contriving their autonomy and sense of ownership (Osborne & Collins, 2000; Toplis, 2011). Yet, teachers are known to think that students should be involved in these procedures (Ottander & Grelsson, 2006). In this study, this involvement was encouraged by asking students to propose and discuss a protocol to test their hypotheses. Although the teachers admitted that they were not used to do this, they appreciated the idea. Most importantly, the students reported that this was very useful for them to make sense of what they could and had to do, even if it demanded more from them than merely following a pre-defined protocol. Another interesting aspect pertains to the students' scaffolding. While a certain degree of cognitive challenge is necessary to stimulate more complex forms of learning, students need to be oriented, introduced to the ideas that they are expected to connect, and given time to integrate all this information (Abrahams & Millar, 2008; Hofstein & Lunetta, 2003; NRC, 2000). Contrasting with reports of students feeling over-challenged because what they had to learn in practical activities was not made clear to them (Haigh, 1993; Holstermann et al., 2010; Lindahl, 2003), this was not an issue for the participant students. The students were provided sufficient background information and guidelines to know what they were meant to do, and throughout the activity, the teachers were constantly reminding them of the purpose of their work and enticing them to reflect and think critically about their observations. Most importantly, the students' themselves mentioned that the introductory session and the instructions with which they were provided were essential for them in this regard. This reinforces the claim that contents must be introduced and addressed along the practical activity, instead of afterwards in an attempt to explain what was observed (Abrahams & Millar, 2008). A post-lab class should, instead, contemplate the discussion of the results obtained and their implications. In this sense, the discussion sessions were regarded by the participants as very fruitful, allowing them to synthesise and recall what they had learned. As for the time granted to develop the activity, this was previously defined with the teachers, who believed it was suitable to perform all the procedures successfully, while accompanying the pace of the students. This latter aspect is very important, since for the students to develop conceptually meaningful understanding, they must have time to interact and think about what they are doing, instead of being overly focused on technical details (Hofstein & Lunetta, 2003; Logar & Savec, 2011).

What procedural skills can students develop through practical work?

Practical work is almost immediately associated with the development of procedural skills. Regardless of any cognitive engagement, the physical manipulation of objects and materials enables students to practice and develop competencies in handling instruments and performing techniques (Bennett, 2003; Hofstein & Lunetta, 2003), which are particularly useful for those who decide to continue their studies by enrolling in science courses. Unsurprisingly, this was another reason presented by the participant teachers for deciding to implement this and other practical activities. Likewise, this aspect also featured on students' motives to endorse practical work and appreciate their participation in this activity, as seen by their responses to the feedback questionnaire. Interestingly, however, according to the interview records, they appeared to doubt the efficacy of practical work per se. The fact that they felt that a context was needed to make the contents more meaningful to them, indicates that the students undermined the purely mechanistic dimension of practical work, which is consistent with previous findings (Toplis, 2011). Elaborate processes of making predictions, observations and interpretations are important competencies that can be extended from the more mechanical skills implicit in practical work (Gott & Duggan, 2007; Wellington, 1998). In fact, besides performing basic laboratory procedures, in this study students formulated hypothesis informed by theory; proposed and discussed an experimental set up to test those hypothesis; made observations, took notes and photos; interpreted and discussed results, under a methodological perspective and within the larger scope of the topics that contextualised the activity; and summarised and applied the knowledge developed in reports and presentations. In addition, although a few students remained too attached to the teachers' and the protocol instructions, there were many who introduced changes in the original protocol.

How do students engage in practical work and how does this affect their experience and learning?

Students' engagement in practical work can occur at two expectably complementary levels: a physical, object-oriented dimension defined by students' hands-on involvement with a given task; and a cognitive, concept- or process-oriented dimension, defined by students' minds-on involvement with that same task (Abrahams, 2011; Taraban et al., 2007; Wellington, 1998). Mediated by the motivational influence that practical work is assumed to have on students, hands-on experiences are expected to enable the transition to a minds-on engagement that can endorse improved cognitive achievements (Bergin, 1999; Taraban et al., 2007). In general, this study's findings meet these assumptions, particularly in what concerns the students' minds-on engagement. Indeed, the observation records and the artifact analysis are indicative of the students' active involvement. This, coupled with the interest expressed in the feedback questionnaire and interviews, is likely to have contributed to the students' cognitive engagement, which ultimate can account for the pre-/post-test improvements registered. Nevertheless, this relationship is not linear, but is instead mediated by a network of factors that require discussion. The first of these factors relates to an arguably contentious issue: the affective value of practical work. Teachers are known to believe that practical work motivates students by stimulating interest, and students usually find it more useful and enjoyable than more passive instructional activities (Abrahams & Saglam, 2010; Cerini et al., 2003; Osborne & Collins, 2000; Toplis, 2011). Unsurprisingly, the participants' opinions matched these ones.

However, since the students' views were self-reported and based on the researchers' observations, it can be argued that, although they seemed to be motivated, this does not mean that they actually were (Abrahams, 2009). And even if they were motivated, which motivational elements were at stake here? Were they truly interested or were they just responding to curricular and instructional demands? And ultimately, did this interest converge into a measurable learning outcome?

While the terms motivation and interest tend to be used interchangeably, they refer to quite different constructs. Motivation is actually a multidimensional construct with intricate layers of complexity, which according to Ryan & Deci (2000)'s model, encompasses both exogenous and endogenous elements. In this study, the students strived to perform the procedures correctly and prepare high-quality reports and presentations, which reflects their concerns about being well succeeded in their biology classes. This can be regarded as an exogenous motivational element that led the students to adopt certain behaviours (Deci, 1992; Ryan & Deci, 2000). Nevertheless, they were also shown to be intrinsically motivated towards the tasks performed (Ryan & Deci, 2000). For instance, in their interviews, many students manifested a personal interest in laboratory work, which is expectable, given that they were science students. Finally, the specificities of the activity can also have contributed to enhance students' interest (Krapp et al., 1992; Schiefele, 2009). Considering that most of them had a limited experience in practical work, it is not surprising that they were excited about engaging in it, thus compelled by a situational interest.

The students' engagement in practice and their interest about it, suggest that their active involvement occurred not only at a physical, but also at a cognitive level. To some extent, this contrasts with previous studies in which hands-on engagement was scantily associated with conceptual learning, and enhanced interest about an issue was not unequivocally linked to enhanced learning (Abrahams & Millar, 2008; Bergin, 1999; Hofstein & Lunetta, 2003). Nevertheless, this association must be interpreted cautiously, as the students who only participated in the lecture also experienced improved understandings at various levels, which reinforces the impact of extrinsic motivational elements.

Conclusion and Implications

More than reinforce the importance of practical work in science education, this study provides an empirical-based analysis of its effectiveness. It demonstrates that practical activities relying in authentic procedures and contextualised in meaningful issues can indeed promote students' engagement and understanding. The findings further sustain that the depth of these educational outcomes depends on factors such as students' personal features, the instructional design of the activities, and the different degrees of orientation and scaffolding provided.

This work details the balance between the limitations and benefits of practical work, which is important to inform the design and enactment of practical activities. Firstly, regarding the degree of structuring and openness of the tasks presented to the students, the findings suggest that guided-inquiry can be a suitable option when there are practical limitations at stake. Practical work can be a costly learning/teaching approach regarding both resources and time to plan and implement the activities. Because the teachers who participated in this study only needed to adapt the resources provided, the planning investment was not a key issue, unlike what frequently happens when teachers opt for inquiry-based practical activities in a stricter sense (Hofstein & Lunetta, 2003; Staer et al., 1998). Furthermore, the way in which the activity was structured and carried out allowed responding to the students' call for guidance without compromising their feeling of ownership (Rudduck & McIntyre, 2007; Toplis, 2011).
Secondly, the outcomes evidence the need for alignment and embedded meaningfulness in practical activities. Although frequently disregarded, the alignment between teachers and students' expectations, instructional design, intended and observed learning outcomes and assessment was determinant in assuring the effectiveness of this practical activity. In addition, the students themselves emphasised that practical work must make sense in a wider curricular or social context. Therefore, when designing a practical activity it is necessary to align, clarify and negotiate its goals, tasks and assessment with the students, and ensure the contextualisation of the activity.

This study raises two main questions that pave the way for future research. The first is related with whether or not the activity fostered long-lasting learning effects. There is no evidence that the knowledge and understanding developed by the students endured past the end of the school-year. A follow-up study would allow understanding what happened in this regard. The second question refers to the influence of the motivational elements introduced by practical work. The affective value of practical work was only tackled in this study to interpret the students' behaviours and clarify particular issues of interest. Nevertheless, this aspect is worth exploring in future studies, especially considering that this is a fruitful line of research that is receiving increasing attention (Abrahams, 2009; Holstermann et al., 2010; Toplis, 2011).

Acknowledgements

The authors are grateful to all the participant students and teachers. MJF and CLS are supported by the FCT fellowships SFRH/BD/37389/2007 and SFRH/BPD/62978/2009, respectively.

References

Abrahams, I. (2009). Does practical work really motivate? A study of the affective value of practical work in secondary school science. *International Journal of Science Education, 31*(17), 2335-2353**.**

Abrahams, I. (2011). *Practical work in secondary science: a minds-on approach*. London/ New York: Continuum International Publishing Group.

Abrahams, I., & Millar, R. (2008). Does practical work really work? A study of the effectiveness of practical work as a teaching and learning method in school science. *International Journal of Science Education, 30*(14), 1945-1969.

Abrahams, I., & Saglam, M. (2010). A Study of teachers' views on practical work in secondary schools in England and Wales. *International Journal of Science Education, 32*(6), 753-768.

Altschul, S. F., Gish, W., Miller, W., Myers, E. W., & Lipman, D. J. (1990). Basic local alignment search tool. *Journal of Molecular Biology, 215*, 403-410.

Bennett, J. (2003). *Teaching and learning science*. New York: Continuum.

Bergin, D. A. (1999). Influences on classroom interest. *Educational Psychologist, 34*(2), 87-98.

Buke, C., Hosgor-Limoncu, M., Ermertcan, S., Ciceklioglu, M., Tuncel, M., Köse, T., & Eren, S. (2005). Irrational use of antibiotics among university students. *Journal of Infection, 51*(2), 135-139.

Cebotarenco, N., & Bush, P. J. (2008). Reducing antibiotics for colds and flu: a student-taught program. *23*(1), 146-157.

Cerini, B., Murray, I., & Reiss, M. (2003). *Student review of the science curriculum. Major findings.* London: Planet Science/Institute of Education University of London/Science Museum. Retrieved from http://www.planet-science.com/sciteach/review.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. New Jersey: Lawrence Erlbaum.

Cohen, L., Manion, L., & Morrison, K. (2007). *Research methods in education* (6th ed.). London; New York: Routledge Falmer.

Crowe, A., Dirks, C., & Wenderoth, M. P. (2008). Biology in Bloom: implementing Bloom's taxonomy to enhance student learning in biology. *CBE-Life Sciences Education, 7*(4), 368-381.

Davey, P., Pagliari, C., & Hayes, A. (2002). The patient's role in the spread and control of bacterial resistance to antibiotics. *Clinical Microbiology & Infection, 8*(s2), 43-68.

Direcção Geral da Inovação e de Desenvolvimento Curricular. (2004). Programa de biologia 12º ano. Curso científico-humanístico de ciências e tecnologias. Lisbon: Ministério da Educação.

Eisenkraft, A., & Anthes-Washburn, M. (2008). Assessment of laboratory investigations. In J. Coffey, R. Douglas & C. Stearns (Eds.), *Assessing science learning: perspectives from research and practice* (pp. 145-165). Arlington VA: NSTA Press.

Fogleman, J., McNeill, K. L., & Krajcik, J. (2011). Examining the effect of teachers' adaptations of a middle school science inquiry-oriented curriculum unit on student learning. *Journal of Research in Science Teaching, 48*(2), 149-169.

Fonseca, M. J., Costa, P., Lencastre, L., & Tavares, F. (2012). Disclosing biology teachers’ beliefs about biotechnology and biotechnology education. *Teaching and Teacher Education, 28*(3), 368-381.

Fonseca, M. J., Costa, P., Lencastre, L., & Tavares, F. (2011). Multidimensional analysis of high school students’ perceptions about biotechnology. *Journal of Biological Education*, 46(3), 129-139.

Fonseca, M. J., & Tavares, F. (2011). Natural antibiotics: a hands-on activity on garlic's antibiotic properties. *American Biology Teacher, 73*(6), 342-346.

Forbes, C. T., & Davis, E. A. (2010). Curriculum design for inquiry: Preservice elementary teachers' mobilization and adaptation of science curriculum materials. *Journal of Research in Science Teaching, 47*(7), 820-839.

Goodwin, C. J. (2009). *Research in psychology: Methods and design*. Hoboken, NJ: John Wiley & Sons.

Gott, R., & Duggan, S. (2007). A framework for practical work in science and scientific literacy through argumentation. *Research in Science & Technological Education, 25*(3), 271-291.

Gravetter, F. J., & Forzano, L. B. (2009). *Research methods for the behavioral sciences* (3rd ed.). Belmont, CA: Wadsworth Cengage Learning.

Grigoryan, L., Burgerhof, J. G. M., Degener, J. E., Deschepper, R., Lundborg, C. S., Monnet, D. L., . . . Haaijer-Ruskamp, F. M. (2007). Attitudes, beliefs and knowledge concerning antibiotic use and self-medication: a comparative European study. *Pharmacoepidemiology and Drug Safety, 16*(11), 1234-1243.

Haigh, M. (1993). “Hands on-minds on”: Introducing openness into senior biology practical work. *Research in Science Education, 23*(1), 110-117.

Hill, T., & Lewicki, P. (2006). *Statistics: methods and applications : a comprehensive reference for science, industry, and data mining*: StatSoft, Inc.

Hofstein, A., & Kind, P. M. (2011). Learning in and from science laboratories. In B. J. Fraser, K. Tobin & C. McRobbie (Eds.), *Second International Handbook of Science Education* (pp. 189-208). Dordrecht: Springer.

Hofstein, A., & Lunetta, V. N. (2003). The laboratory in science education: foundations for the twenty-first century. *Science Education, 88*(1), 28-54.

Holstermann, N., Grube, D., & Bögeholz, S. (2010). Hands-on activities and their influence on students’ interest. *Research in Science Education, 40*(5), 743-757.

House of Commons Science and Technology Committee. (2002). *Third report. Science education from 14 to 19.* London: HMSO Retrieved from http://www.publicationsparliament.uk/pa/cm200102/cmselect/cmsctech/508/50802.htm.

Hume, A., & Coll, R. (2008). Student experiences of carrying out a practical science investigation under direction. *International Journal of Science Education, 30*(9), 1201-1228.

Jenkins, E. W. (1999). Practical work in science - some questions to be answered. In Leach J. & A. Paulsen (Eds.), *Practical work in science education: recent research studies* (pp. 19-32). Roskilde/Dordrecht: Roskilde University Press/Kluwer.

Jones, M. G., & Rua, M. J. (2008). Conceptual representations of flu and microbial illness held by students, teachers, and medical professionals. *School Science and Mathematics, 108*(6), 263-278.

Kidman, G. (2008). Asking students: What key ideas would make classroom biology interesting? *Teaching Science, 54*(2), 34-38.

Krapp, A., Hidi, S., & Renninger, K. A. (1992). Interest, learning and development. In K. A. Renninger, S. Hidi & K. , A. (Eds.), *The Role of interest in learning and development.* (pp. 3-26). Hillslade, NJ: L. Erlbaum Associates.

Krippendorff, K. (2004). *Content analysis: an introduction to its methodology*. Thousand Oaks, California: Sage Publications, Inc.

Lawson, M. A. (2008). The Antibiotic Resistance Problem Revisited. *American Biology Teacher, 70*(7), 405-410.

Lindahl, B. (2003). Pupils' responses to school science and technology? A longitudinal study of pathways to upper secondary school. *Gőteborg: Acta Universitatis Gothoburgensis***.**

Logar, A., & Savec, V. F. (2011). Students' hands-on experimental work vs lecture demonstration in teaching elementary school chemistry. *Acta Chimica Slovenica, 58*, 866–875.

Lord, T., & Baviskar, S. (2007). Moving students from information recitation to information understanding: Exploiting Bloom's Taxonomy in creating science questions. *Journal of College Science Teaching, 36*(5), 40-44.

Maniotes, L. K., Caspari, A. K., & Kuhlthau, C. C. (2007). *Guided Inquiry Learning in the 21st Century*. Westport, CT: Libraries Unlimited.

McNulty, C. A. M., Boyle, P., Nichols, T., Clappison, P., & Davey, P. (2007a). Don't wear me out--the public's knowledge of and attitudes to antibiotic use. *Journal of Antimicrobial Chemotherapy, 59*(4), 727-738.

McNulty, C. A. M., Boyle, P., Nichols, T., Clappison, P., & Davey, P. (2007b). The public's attitudes to and compliance with antibiotics. *Journal of Antimicrobial Chemotherapy, 60*(suppl_1), 63-68. doi: 10.1093/jac/dkm161

Milandri, M. (2004). Children's views of microbes - Current beliefs about bacteria in Italian grade school children. *Pediatric Infectious Disease Journal, 23*(12), 1077-1080.

Millar, R. (1998). Rhetoric and reality. What practical work in science education is *really* for. In J. J. Wellington (Ed.), *Practical work in school science: which way now?* (pp. 16-31). London: Routledge.

Millar, R., Le Maréchal, J. F., & Tiberghien, A. (1999). 'Mapping' the domain: Varieties of practical work. In D. Psillos & H. Niedderer (Eds.), *Teaching and learning in the science laboratory* (pp. 33-59). Dordrecht: Kluwer Academic Publishers.

Moore, B., & Stanley, T. (2009). *Critical thinking and formative assessments: increasing the rigor in your classroom*: Eye on Education.

National, Association, of, Biology, & Teachers. (2005). *Role of laboratory and field instruction in biology education.*: Retrieved from http://www.nabt.org/sites/S1/index.php?p=67.

National Research Council. (1996). *National science education standards*. Washington, DC: National Academy Press.

National Research Council. (2000). How people learn: brain, mind, experience, and school. Washington, DC: National Academy Press.

Oppenheim, A. N. (1992). *Questionnaire design, interviewing and attitude measurement* (New ed.). London; New York: Continuum.

Osborne, J. (1998). Science education without a laboratory. In J. Wellington (Ed.), *Practical work in school science: Which way now?* (pp. 156-173). London: Routledge.

Osborne, J., & Collins, S. (2000). *Pupils' and parents' views of the school science curriculum* London: Kings College London.

Ottander, C., & Grelsson, G. (2006). Laboratory work: the teachers' perspective. *Journal of Biological Education, 40*(3), 113-118.

Plowright, D. (2011). *Using Mixed Methods: Frameworks for an Integrated Methodology*. London: SAGE Publications.

Psillos, D., & Niedderer, H. Issues and questions regarding the effectiveness of labwork. In D. Psillos & H. Niedderer (Eds.), *Teaching and learning in the science laboratory* (pp. 21-31). Dordrecht: Kluwer Academic Publishers.

Randler, C., & Hulde, M. (2007). Hands-on versus teacher-centred experiments in soil ecology. *Research in Science & Technological Education, 25*(3), 329-338.

Rudduck, J., & McIntyre, D. (2007). *Improving learning through consulting pupils*. New York: Routledge.

Ryan, R. M., & Deci, E. L. (2000). Intrinsic and extrinsic motivations: Classic definitions and new directions. *Contemporary Educational Psychology, 25*(1), 54-67.

Sadler, T. D. (2009). Situated learning in science education: socio-scientific issues as contexts for practice. *Studies in Science Education, 45*(1), 1 - 42.

Schiefele, U. (2009). Situational and individual interest. In K. R. Wentzel & A. Wigfield (Eds.), *Handbook of motivation at school* (pp. 197-223). New York: Routledge.

Staer, H., Goodrum, D., & Hackling, M. (1998). High school laboratory work in Western Australia: Openness to inquiry. *Research in Science Education, 28*(2), 219-228.

Steele, F., & Aubusson, P. (2004). The Challenge in Teaching Biotechnology. *Research in Science Education, 34*, 365-387.

Tamura, K., Peterson, D., Peterson, N., Stecher, G., Nei, M., & Kumar, S. (2011). MEGA5: Molecular evolutionary genetics analysis using maximum likelihood, evolutionary distance, and maximum parsimony methods. *Molecular Biology and Evolution, 28*, 2731-2739.

Taraban, R., Box, C., Myers, R., Pollard, R., & Bowen, C. W. (2007). Effects of active-learning experiences on achievement, attitudes, and behaviours in high school biology. *Journal of Research in Science Teaching, 44*(7), 960-979.

Thorne, K., & Mackey, D. (2007). *Everything you ever needed to know about training: a one-stop shop for everyone interested in training, learning and development*. London: Kogan Page.

Tibell, L. A. E., & Rundgren, C.-J. (2010). Educational challenges of molecular life science: characteristics and implications for education and research. *CBE-Life Sciences Education, 9*(1), 25-33.

Toplis, R. (2011). Students' views about secondary school science lessons: The role of practical work. *Research in Science Education, 42*(3), 1-19.

Weber, R. P. (1990). *Basic content analysis*. Newbury Park, CA: Sage Publications, Inc.

Weil, D. K., & Kincheloe, J. L. (2004). *Critical thinking and learning: an encyclopedia for parents and teachers*. Westport, CT: Greenwood Press.

Wellington, J. (2005). Practical work and the affective domain: What do we know, what should we ask, and what is worth exploring further? In S. Aslop (Ed.), *Beyond cartesian dualism. encountering affect in the teaching and learning science* (pp. 99-110). Dordrecht: Springer.

Wellington, J. J. (1998). *Practical work in school science: which way now?* London: Routledge.

Supporting information

Table VI.S5
Pre-/post-test and scoring rubrics.

Bloom's Level	Criteria	Points	Qualitative classifier
Q2. What is an antibiotic and how does it work?			
Knowledge (LO) Comprehension (LO)	• No answer • Only incorrect notions • More incorrect than correct notions • Unfocused/Unrelated response	0	Inadequate/ failing effort
	• Only one correct notion; none incorrect • Two correct notions; one incorrect	1	Impaired/ minimum effort
	• Two correct notions • Three, four or five correct notions; one, two or three incorrect	2	Needs much improvement/ low effort
	• Three correct notions; none incorrect • Four or five correct notions; one or two incorrect	3	Needs improvement/ effort
	• Four correct notions; none incorrect • Five correct notions; one incorrect	4	Adequate/ good effort
	• Five correct notions; none incorrect • Six or more correct notions; one incorrect	5	High achievement/ high effort
	• Six or more correct notions; none incorrect	6	Outstanding achievement/ very high effort
Q3. What traits are desirable in an antibiotic compound? **Q6. List measures that can be used to avoid or reduce antibiotic resistance.**			
Bloom's Level	Criteria	Points	Qualitative classifier
Knowledge (LO) Comprehension (LO) Application (HO) Evaluation (HO)	• No answer • Only incorrect notions • More incorrect than correct notions • Unfocused/Unrelated response	0	Inadequate/ failing effort
	• Only one correct notion; none incorrect • Two correct notions; one incorrect	1	Impaired/ minimum effort
	• Two correct notions • Three, four or five correct notions; one, two or three incorrect	2	Needs much improvement/ low effort
	• Three correct notions; none incorrect • Four or five correct notions; one or two incorrect	3	Needs improvement/ effort
	• Four correct notions; none incorrect • Five correct notions; one incorrect	4	Adequate/ good effort
	• Five correct notions; none incorrect • Six or more correct notions; one incorrect	5	High achievement/ high effort
	• Six or more correct notions; none incorrect	6	Outstanding achievement/ very high effort

"Don't know" answers were considered as "No answer" and attributed no points.

Table VI.S5 (continued)

Q4. Which are the procedures involved in the production of antibiotic drugs?
Q5. What is the meaning of antibiotic resistance?

Bloom's Level	Criteria	Points	Qualitative classifier
Knowledge (LO) Comprehension (LO) Application (HO)	• No answer • Only incorrect notions • More incorrect than correct notions • Unfocused/Unrelated response	0	Inadequate/ failing effort
	• Only one correct notion; none incorrect • Two correct notions; one incorrect	1	Impaired/ minimum effort
	• Two correct notions • Three, four or five correct notions; one, two or three incorrect	2	Needs much improvement/ low 3effort
	• Three correct notions; none incorrect • Four or five correct notions; one or two incorrect	3	Needs improvement/ effort
	• Four correct notions; none incorrect • Five correct notions; one incorrect	4	Adequate/ good effort
	• Five correct notions; none incorrect • Six or more correct notions; one incorrect	5	High achievement/ high effort
	• Six or more correct notions; none incorrect	6	Outstanding achievement/ very high effort

Q8. Antibiotics act on bacteria, fungus and virus. (T/F/DK)
Q9. The antibiotic compounds that we use only eliminate pathogenic agents (T/F/DK)
Q10. The antibiotic compounds that we use may be toxic for our own cells (F/F/DK)
Q11. The antibiotic compounds that we used are produced artificially in laboratories (T/F/DK)
Q12. Antibiotics are used specifically to relieve pain (T/F/DK)
Q13. Antibiotics are used specifically to relieve fever (T/F/DK)
Q14. Antibiotics are used specifically to treat cold and flu (T/F/DK)
Q16. There must be cell division for antibiotic resistance to be transferred between bacteria (T/F/DK)

Bloom's Level	Criteria	Points	Qualitative classifier
Knowledge (LO) Application (HO) Analysis (HO) Evaluation (HO)	• No answer • Only incorrect notions	0	Inadequate/ failing effort
	• True; only correct notions • False; no correct notions • False; one correct notion but one incorrect	1	Impaired/ minimum effort
	• False; one correct notion • False; two or three correct notions, but one or two incorrect	2	Needs improvement/ effort
	• False; two correct notions and none incorrect • False; three correct notions, but one more incorrect	3	Adequate/ good effort
	• False; three correct notions and none incorrect • False; more than three correct notions, but one or two incorrect	4	High achievement/ high effort
	• False; four or more correct notions, and none incorrect	5	Outstanding achievement/ very high effort

"Don't know" answers were considered as "No answer" and attributed no points.

Table VI.S5 (continued)

Q17. Nowadays, it is safe to admit that bacterial infectious diseases are under control (1-totally disagree to 5 - totally agree)
Q18. It is adequate to use an antibiotic without prescription when… (1-totally disagree to 5 - totally agree):a) …we do not have time to go to the doctor; b) …we are in vacation in another country; c) … the appointment is too expensive; d) …we already know the antibiotic because we have used it before; e) …our friends are used to using it and it works for them; f) …we ask for the pharmacist's advice.
Q19. When we are sick (for instance with flu), it is adequate to use an antibiotic to prevent other, more serious diseases (1-totally disagree to 5 - totally agree)
Q20. The length of treatment with antibiotics must be… (1-totally disagree to 5-totally agree): a) …until the package is finished; b) …until the symptoms disappear; c) …compatible with the physician's instructions.

Bloom's Level	Criteria	Points	Qualitative classifier
Knowledge (LO) Application (HO) Analysis (HO) Evaluation (HO)	• No answer • No justification or only inadequate notions • Same amount of reasonable and unreasonable notions	0	Inadequate/ failing effort
	• Only one reasonable notion • Two or three reasonable notions, but one or two unreasonable	1	Impaired/ minimum effort
	• Two reasonable notions and none unreasonable • Three or four reasonable notions, but one or two unreasonable, respectively	2	Needs improvement/ effort
	• Three reasonable notions and none unreasonable • Four reasonable notions and one unreasonable • More than four reasonable notions, but two or more unreasonable	3	Adequate/ good effort
	• Four reasonable notions and none unreasonable • Five or more reasonable notions and one unreasonable	4	High achievement/ high effort
	• Five or more reasonable notions and none unreasonable	5	Outstanding achievement/ very high effort

"Don't know" answers were considered as "No answer" and attributed no points.

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CHAPTER VII

General Discussion

Chapter VII

General Discussion

A picture of the effectiveness of innovative educational resources in biotechnology education

With the incessantly emphasised calls for public participation in science and technology affairs, the contribution of biotechnology for scientific and technological development, and its growing societal impact, the endeavours to promote biotechnology education are likely to continue and be strengthened (Allen & Hodd, 2000; Braun & Moses, 2004; France, 2003; Ramón, Diamante, & Calvo, 2008). Biotechnology is a socioscientific issue that is particularly prone to controversy, given the plethora of moral and affective matters it raises (Amin, Jahi, Nor, Osman, & Mahadi, 2007; Fitzsimons, 2007; Sagar, Daemmrich, & Ashiya, 2000). These issues are often bolstered by misconceptions about the scientific notions underlying biotechnology applications, which can be challenging for non-expert citizens (Amin et al., 2007; Lewis & Kattman, 2004; Shaw, Van Horne, Zhang, & Boughman, 2010; Tibel & Rundgren, 2010). Therefore, the importance of raising scientific literacy about biotechnology is ever so pressing in the context of science education.

Taking the above into consideration, the main goal of this project was to assess the efficacy of innovative resources in the promotion of elementary and high school students' scientific literacy about biotechnology. Achieving this goal required the thorough characterisation of the perceptions held by students and teachers, i.e. the stakeholders in the teaching/ learning process. In addition, it also demanded the knowledge about the curricular objectives and guidelines concerning this topic and the competencies that the students are expected to develop during the instructional levels considered.

The outcomes of the work carried out during this project are detailed and discussed in the previous chapters of this thesis. The goal of this Chapter is to provide a transversal discussion and highlight the main conclusions drawn concerning the most relevant issues brought to the fore during the development of the project. It is intended to present a global overview of the novel body of information that can advance the current knowledge on the topic at national and international levels, and to evidence its implications for future research and practice.

Setting starting points: getting hold of the network of factors that mediate students' perceptions about biotechnology

The importance of diagnosing students' preconceptions, values, emotional and affective responses, and a plethora of other elements that they bring into the learning process is now well-established (Bransford & Donovan, 2005; Concannon, Siegel, Halverson, Freyermuth, 2010; Koba & Tweed, 2009). It is recognised that these elements shape students' learning, determining the effectiveness of the instructional interventions put forth (Concannon et al., 2010; Grubb & Cox, 2005; Siti Hendon & Khalijah, 2007). In the case of biotechnology, a socio-scientific issue that gathers so much media attention, the diagnostic of students' perceptions is particularly important. In this regard, while several studies have provided rapports of students' knowledge and attitudes, the assessment of discrete elements arguably fails to provide a holistic, more integrated picture of how these elements interact to condition students' learning.

The work presented and discussed in Chapter 3 supports previous reports on students' limited or superficial knowledge about basic processes (Dawson, 2007; Prokop, Lesková, Kubiatko, & Diran, 2007; Uşak, Erdogan, Prokop, & Özel, 2009), their diversified range of attitudes towards biotechnology pending on the purpose of the applications or the type of organism manipulated (Klop & Severiens, 2007; Sáez, Niño, & Carretero, 2008), and, albeit not straightforward, the correlation between knowledge and attitudes (Dawson, 2007; Klop & Severiens, 2007; Lamanauskas & Makarskaitė-Petkevičienė, 2008; Prokop et al., 2007; Uşak et al., 2009). Most importantly, this study demonstrates the interconnectedness of conceptual, attitudinal and motivational elements that mediate the influence of knowledge on students' perceptions. The data gathered here provide empirical evidence to support the argument that biotechnology education must go beyond the promotion of knowledge, whilst also addressing these other factors that also play a part in the development of scientific literacy (Klop & Severiens; Sáez et al., 2008; Sturgis, Cooper, & Fife-schaw, 2005), which, in turn, inform the design of teaching materials and interventions. In practical terms, it is necessary to assure that the features of educational activities and interventions address specific requirements that appeal to the students and meet their needs. Amongst the most relevant aspects to consider in this regard, is the meaningfulness of the contents, which constitutes a key aspect emphasised in syllabuses and studies in different countries (Bennett, Lubben, & Hogarth, 2007; Dori, Tal, & Tsaushu, 2003; Drechsel, Carstensen, & Prenzel, 2011; France, 2007; Pintrich, 2003; Spector & Yager, 2010; Topcu, Sadler, & Yilmaz-Tuzun, 2010). The findings presented in

Chapter 3 contributed to the optimisation of the activities described in Chapter 5, with the purpose of ensuring the coverage of contents that, in addition to being framed within the biology curriculum, were informative, up to date and relevant for the students.

In this sense, we proposed a laboratory activity on the testing of natural antibiotics, contextualised by the unquestionably pressing public health issue that is antibiotic resistance. As admonished by Lawson (2008), given the global threat that it represents, antibiotic resistance is an issue that must be discussed in the classroom. The exploration of the antibiotic properties of naturally occurring phytoactive compounds has been identified by Kidman (2010), as an activity which the students perceive as particularly interesting. Students' feedback gathered in the course of the work described in Chapter 6 evidences the importance of the framework of the practical activity. In their statements, students stressed that the context and the background information provided to them were essential to motivate them to engage in the procedures proposed and help them understand the significance of the activity and of the underlying phenomena. These results emphasise the need to discuss the goals, tasks and assessment of a given activity with the students (Abrahams & Millar, 2008; Ottander & Grelsson, 2006), and to address topics that are important and interesting to them (Hofstein, Eilks, & Bybee, 2011). Practical procedures must allow answering one or more questions and/or help to understand a scientific concept (Mohrig, 2004). Therefore, when designing a practical activity one must acknowledge that depriving students of a context is undernourishing their call for meaningfulness, which can hamper their cognitive engagement.

The interactive network of elements that shapes students' perceptions appears to operate regardless of gender and education profile specificities (Chapter 3), which means the aspects pointed out so far must be accounted for when considering different instructional levels and settings, whilst not dismissing the need to attend to particular features, as the students' instructional level or academic area. Furthermore, the outcomes of the multidimensional analysis suggest careful attention should be paid in setting up measures that respect these interactions while targeting specific educational goals. In this regard, although the research conducted so far has predominantly focused on science students, the purpose of including non-science students in this study sample was to gauge the effectiveness of the science curricula coverage of biotechnology topics by cross-comparing their responses with the science students' (Dawson, 2007; Lamanauskas & Makarskaitė-Petkevičienė, 2008; Prokop, et al., 2007), and gather information required for the development of strategies to improve the scientific literacy of these students, who will also be called upon to decide on scientific issues.

Another implication of these findings pertains to the differences observed between the perceptions of high school students and elementary students. AS illustrated in Chapter 2, the questionnaire developed to assess students' perceptions was validated in a sample of high school and elementary students. Although Chapter 3 reports data on high school students only, elementary students' perceptions were assessed as well. Overall, the analysis of the responses of 498 9th grade students (mean age=14.34 ±=0.66; 56% females) revealed their knowledge and attitudes were identical (p>0.05) to the knowledge and attitudes of the 12th grade students who were not attending science courses. The similarity between the levels of knowledge demonstrated by the 9th graders and the non-science 12th graders, suggests that the maturity of the older students not engaged in a science curriculum did not translate in an active search for information that could provide them with more knowledge. Indeed, although the development of interest about abstract issues, such as biotechnology, has been observed to increase with age (Baram-Tsabari & Yarden, 2009), these students were less interested in biotechnology than 9th graders, and were also the ones attributing the least importance to its applications. Hence, informed by this project, future interventions to improve both science and non-science students' scientific literacy about biotechnology cannot strive to increase their knowledge without ensuring the enhancement of their intrinsic or at least, extrinsic motivation (Pintrich, 2003; Yen, Tuan, & Liao, 2010).

Whereas it was intended to extend the range of activities envisioned to the 9th grade, we limited the focus of our interventions to the 12th grade, a decision based on the feedback gathered from the teachers who participated in the project and prospective participants approached during the recruitment phase. Considering the tight schedule allocated to natural sciences classes at the 9th grade, the limited weight of biotechnology in the elementary curriculum comparatively to other subjects, and the length of that curriculum, teachers felt that it would be unfeasible to invest in practical activities on this topic, although all of them valued their expectable educational benefits. The reasons pointed out by the teachers are not new, as it is known that the extensiveness of the curriculum, especially when running on a tight schedule, can preclude teachers' attempts at enacting with more innovative, active learning-based activities, which are more time consuming than less practical activities (Hofstein & Lunetta, 2003; Kidman, 2008; Ottander, & Gresslon 2006; Steele & Aubusson, 2004). Hence, it is necessary to search for ways in which these and other laboratory activities can be efficiently implemented in such constrained contexts.

Knowing your cards: understanding how teachers cope with the challenges of biotechnology education

While the number of studies focusing on adult populations' perceptions of biotechnology is considerably larger than the studies focusing on young people, the ones targeting specifically teachers are even scarcer than the latter (Bryce & Gray, 2004; Gardner & Jones 2010; Sorgo & Ambrozic-Dolinsek, 2010; Topcu et al., 2010). However, as teacher are privileged mediators of the education of future generations, consulting them and understandings the challenges they face when engaging in such a demanding subject as biotechnology, is of paramount importance (Bryce & Gray, 2004; Falk, Brill, & Yarden, 2008; Gardner & Jones, 2010; Steele & Aubusson, 2004). Knowledge about the ways in which teachers perceive biotechnology and biotechnology education is essential to ensure the viability of the educational interventions planned. In this project, the practitioners' feedback was necessary to ensure the establishment of the collaborations required to implement the activities in classroom settings. But, most importantly, it was a pivotal input to the development of those activities to make sure that they would adequately fit into a classroom context, with all the associated specificities and constraints. Furthermore, it strengthened the idea that the long-term efficacy of any educational program relies on the teachers' ongoing efforts, their will and competencies to continue to explore it autonomously without outside intervention (Beyer & Davis, 2012; Cochran-Smith, Feiman-Nemser, & McIntyre, 2008; Knobloch, 2006; Kyriakides & Kelly, 2003). For this to be possible, the research findings must contribute to facilitate the connection between research and practice.

The work described in Chapter 4 has sought to identify criteria for the development of educational resources and activities in the short-run and, in the longer-run, to pinpoint areas of intervention for focused teacher training programs.

Overall, the findings from the teacher survey conducted are in line with previous reports (Bryce & Gray, 2004; Steele & Aubusson, 2004). The data gathered reinforce the observed tendency for teachers to acknowledge the importance and interest of biotechnology and biotechnology education, but at the same time report a range of obstacles to the teaching of biotechnology contents. By correlating teachers' beliefs about biotechnology education with their beliefs about biotechnology, it was possible to understand that their subject matter beliefs did not impact negatively on their practice (Chapter 4). Instead, as previously discussed, these teachers overestimated the unavailability of resources to carry out practical work in the scope of biotechnology. Whilst there are many teaching materials purposely conceived for elementary and high school levels (Chapter 1), teachers seem to access only a limited number of information sources to keep informed about the novelties on these topics, which suggests teachers' unawareness of existing materials and stresses the importance of educational programs to improve their information literacy skills (Sun & Liu, 2009; Williams & Coles, 2007).

The most surprising outcome of the study is teachers' beliefs on how their students' perceive biotechnology education (Chapter 4). Contrary to what one would expect considering previous research (Falk et al., 2008; Steele & Aubusson, 2004), teachers believed the topics covered in the curriculum (Chapter 1) are accessible to students. Moreover, and in line with the 12^{th} grade biology students' responses (Chapter 3), they thought these issues are appealing to the students.

This information was applied to the design of the activities presented in Chapters 1, 5 and 6, which were planned with the aim of being interesting to both teachers and students, as well as time and cost-efficient, to meet teachers' concerns about the schedule and resource limitations encountered in most schools. The use of alternative protocols allowed dismissing specialised laboratory settings and materials, overcoming the handicaps most frequently mentioned by the teachers.

Teachers' feedback was important at every stage of this project, not only during the diagnostic stages, but particularly throughout the activity validation. Therefore, the teachers who participated in the validation phase depicted in Chapter 6 were asked to implement the activities themselves, which contributed to lessen the interference with the typical classroom environment (Ware & Johnson, 2000; Wragg, Wikeley, Wragg, & Haynes, 1996). Furthermore, the teachers were also asked to give their feedback on the activity. Interestingly, from the interview data (Chapter 6), their opinions were consistent with the students'. In addition to agreeing on the relevance of antibiotic use and resistance, teachers considered that the adaptation of the materials and techniques according to their school's conditions provides a more realistic experience and fosters the development of creativity and critical skills. This reinforces the added value of alternative protocols (Costa, 2007; Shimabukuro & Haberman, 2006; Wassmer, Kipe-Nolt, & Chayko, 2006), and sustains the feasibility of laboratory activities in common high schools.

Finally, it is worth mentioning the empowerment of teachers to conduct practical activities such as the ones introduced in the course of this project. The validation of the activities in schools took place during the second and third trimesters of the 2010/2011 academic year. The teachers were provided with all the supporting materials and encouraged to continue to implement the activity whenever they deemed appropriate and share the information with their colleagues. In fact, teachers can easily access these materials at the Casa das Ciências website (Compostos fitoactivos - o efeito antibiótico do alho, http://www.casadasciencias.org/). So far, it was brought to our attention that at least one of the teachers who participated in the study repeated the activity this academic year (2011/2012) with her 12th grade biology students, achieving excellent results. This foretells promising expectations for the impact of future teacher workshops on hands-on activity development and implementation.

To trust or not to trust: teachers' and students' use and trust in information sources about biotechnology

Schools have been asked to play a central role in the promotion of information literacy, by enabling students to mobilise accurate and up-to-date information in the development of scientifically sustained knowledge required for public participation in decision-making processes about socio-scientific issues (Branch, 2003; Elliot, 2006; Julien & Barker, 2009; Ward & Hockey, 2007). Biotechnology's pervasive and frequently biased coverage in the media makes it an interesting topic to infer students' and teachers' information literacy skills. The complex and abstract nature of the knowledge required to understand biotechnology-related issues renders many citizens feeling incapable or unwilling to engage with them (Bonfadelli, 2005; Gaskell, et al., 2006). As a result, many individuals will form their opinions mainly relying on values and interpretations made by sources that they consider reliable (Brossard & Nisbet, 2007: Ho, Brossard, & Scheufele, 2008; Savadori et al., 2004; Siegrist, 2000). Therefore, it is important to understand how the perception of trust and reliability influences the selection of information sources about biotechnology. In this context, it is worth discussing the main findings resulting from the assessment of the association between teachers and students' *use of* and *trust in* information sources about biotechnology (Fonseca, Costa, Lencastre, & Tavares, communication, August 30, 2011).

It was observed that school textbooks, scientific magazines and the television were among the main sources used by teachers and students to retrieve information about biotechnology. This data revealed that the availability of the information source may have a stronger influence than its reliability on both the teachers' and the students' choices. For instance, although the internet and the media were selected as frequently used information sources by 86% and 60% of the teachers respectively, they were uncertain about the reliability of the information conveyed therein (Fonseca, Costa, Lencastre, & Tavares, communication, August 30, 2011). Likewise, while over 70% of the students, regardless of their academic-profile (p=0.107), mentioned they frequently used the television, they also placed a limited trust in the information provided.

Consistently with previous reports (Brossard & Nisbet, 2007; Pouliot, 2010), the respondents revealed a seeming deference to scientific authority, by consistently pointing out scientific magazines and scientists as the most reliable providers of information. In contrast, the respondents were manifestly reluctant to trust other stakeholder groups involved not only in the mediation of information, but also in regulation and legislation, such as governmental agencies and, particularly, politicians (Fonseca et al., communication, August 30, 2011).

Interestingly, whereas for the non-biology and the non-science students, the television was indeed the most frequently selected source, teachers and school textbooks were reportedly more relevant for biology students. According to this outcome, it could be expected that these students' trust patterns would be influenced by the teachers'. However, the results suggested otherwise. In spite of some academic profile-related differences, the trust patterns for the biology students were closer to the ones observed for the students of the other academic profile-based groups, than to the teachers'. The fact that both students and teachers selected the most easily available sources of information may be related with a deficit in information literacy instruction, as described in previous studies (Branch, 2003; Julien & Barker, 2009; Sun & Liu, 2009; Sundin & Francke, 2009; Wan & Gut, 2009).

In previous studies, teachers have been shown to frequently restrict their search for information to the most readily available sources, as a result of time constraints and/or lack of skills to properly evaluate them (Halverson, Siegel, & Freyermuth, 2010; Sun & Liu, 2009; Williams & Coles, 2007). As discussed in Chapter 4, trust is discretely related to teachers' decision to use a given information source. The inexistence of a clear relationship between the use of information sources by teachers and students, suggests the need for increased teacher engagement in information literacy instruction. Therefore, as argued in Chapter 4, this reinforces the perception that it is important to create opportunities for the promotion of teachers' own information literacy, and recommendations to assist them in scaffolding the development of these competencies by their students. The development of information literacy skills, required for lifelong learning, is essential to enable the students to critically evaluate the information from various sources, thus preparing them for their participation in cultural and civic affairs (Doyle, 1994; Julien & Barker, 2009; Ward & Hockey, 2007).

Reaching compromises: can guided-inquiry be a more realistic alternative than authentic inquiry in biotechnology education?

The success of any educational activity depends upon its adaptation to the specificities of the target audience (Calley, 2010; Persico & Manca 2000). When seeking to promote scientific literacy about biotechnology amongst elementary and high school students, it is necessary to assure that the strategies put forth are adapted to their real learning conditions. This implies attending to their socio-demographic profile and background, and to the academic competencies that these students are expected to develop along the instructional levels considered.

Therefore, the design or adaptation of teaching-learning activities requires their curricular contextualisation (Bennet et al., 2007; Hofstein & Lunetta, 2003; Phillips, Robertson, Batzli, Harris, & Miller, 2008), an aspect that was heeded in this project. The analysis of the biotechnology-related contents in the guidelines of the Portuguese Ministry of Education was necessary to frame the interventions outlined. Disregarding this aspect when planning to intervene on formal science education can subvert the efficacy of the activities developed (Hofstein & Lunetta, 2003; Ottander & Grelsson, 2006). When those activities are to be enacted by the teachers, it can also clash with the methodologies originally envisioned by them, and compromise their practice (Dagenais, Moore, & Sabat, 2009). In the case of informal science education, this contextualisation also proves beneficial (Bell, 2009; Van Mil, Boerwinkel, Buizer-Voskamp, Speksnijder, & Waarlo, 2010), although such environments are not obliged to convey resources and activities utterly aligned with the contents foreseen in academic curricula (Braund & Reiss 2006; Fenichel & Schweingruber, 2010).

In this project, the activities developed and implemented were shown to be effective at different levels, consistently with the expected outcomes highlighted by the participant teachers (Chapter 6), and outlined for the implementation of practical work (Abrahams, 2009; Abrahams & Millar, 2008; Cerini, Murray, & Reiss, 2003; Hofstein & Lunetta, 2003; Holstermann, Grube, & Bögeholz, 2010; Toplis, 2011). In fact, the data gathered demonstrated effects concerning:

- the enhancement of students' awareness and understanding about abstract concepts and processes related with several curriculum-associated contents, such as the notion of bacteria and antibiotics;
- the improvement of students' procedural skills, which is a highly appreciated learning outcome; and
- students' motivation to engage in the tasks proposed, an issue discussed in more detail below.

As discussed in Chapter 6, the effectiveness of the activities implemented was necessarily linked to its instructional design and to the way in which it was carried out. From the aspects to consider, a particularly important element refers to the nature of inquiry underlying the implementation of the activity in schools.

As opposed to traditional step-by-step, recipe-like laboratory work, current science syllabuses emphasise the importance of engaging students in authentic forms of inquiry-based activities (DGIDC, 2004; House of Commons Science and Technology Committee, 2002; NABT 2005; NRC, 1996). In general, while the first type of activities tends to promote mechanistic and rote learning, inquiry-based learning is valued by its expected ability to acquaint students with the process of scientific inquiry (Cuevas, Lee, Hart, & Deaktor, 2005; Hume & Coll, 2008; Kerfeld, Levis, & Perry, 2001; William & Sandoval, 2004). Nevertheless, inquiry-based activities can be rather demanding in regards to time and resources, which can be discouraging for teachers who have to balance extensive curricula with tight calendars and schedules (Abrahams & Saglam, 2009; Hofstein & Lunetta, 2003; Osborne, 1998; Ottander & Grelsson, 2006; Scharfenberg & Bogner, 2010). This can explain why inquiry-based learning still fails to be widely incorporated in science instruction (Hanegan & Bigler, 2010; Steele & Aubusson, 2004).

For these reasons, the implementation of the activities was discussed with the teachers to ensure that both them and the students were granted all the orientation and guidance necessary, while still giving room to engage in discussion and speculation about the strategies more suitable to answer a specific question or problem with global societal implications. In this sense, the teaching approach used was closer to what has been described as guided inquiry (Eisenkraft & Anthes-Washburn, 2008; Maniotes, Caspari, & Kuhlthau, 2007). According to the degree of structure in science lessons, inquiries can be classified as guided or open (Hanegan & Bigler, 2010), if they are more or less structured, respectively.

Although the degree of openness of an inquiry-based activity is a determining factor of the creative and critical thinking skills that the activity can foster (Hume & Coll, 2008), the intention here was to reach a compromise between the students' planning and discussion of experimental set-ups and the instructiveness of the tasks proposed (Hofstein & Lunetta, 2003; Osborne & Collins, 2000; Ottander & Grelsson, 2006; Toplis, 2011). According to both the students and the teachers' feedback, this goal was attained. Indeed, the participants felt that the activities successfully balanced the learning objectives and outcomes and the investment concerning time and resources (Chapter 6).

Interestingly, the students' reports and interviews indicate that they valued the guidance (Chapter 6). Therefore, it can be argued that guided inquiry may contribute to regulate the levels of cognitive challenge of practical activities, assuring a more efficient management of the contents and tasks by the students, as emphasised in previous studies (Abrahams & Millar, 2008; Bransford, 2000; Hofstein & Lunetta, 2003; Haigh, 1993; Holstermann et al., 2010; Lindahl, 2003). Because this project did not comprise the comparative assessment of diverse types of inquiry, it cannot add on whether these oriented activities are more or less effective than open-ended investigations, as these are undoubtedly different teaching-learning approaches (Haigh 1993; Hanegan & Bigler, 2010). Instead, the results obtained in the course of this project provide empirical evidence on the efficacy of an alternative to those approaches. Indeed, these findings sustain the effectiveness of a model that meets students' and teachers' needs, enabling meaningful learning in common high school contexts in which the usually suboptimal conditions frequently constrain more ambitious instructional proposals (Smithenry, 2010).

In and out of the classroom: how does context influence the impact of biotechnology education activities?

The activities presented herein were validated in formal and informal settings (Chapter 6). Although in both cases the global theme underlying the activity was bacterial resistance to antibiotic drugs, the instructional design was purposely devised to attend to the characteristics of the participants, settings, and objectives in each situation. As described in Chapter 6 (see Fig. VI.1 and VI.S2), the UJr's project *Microbiology recipes: antibiotics à la carte* was a one week long program that included the two activities on antibiotics implemented in classroom contexts (Fig. VII.1). The data gathered through the assessment of the activity in these two contexts, in addition to the implications already detailed in Chapter 6, provide an interesting basis for comparing the impact of context on students' motivation and performance.

Before entering this discussion, there are two aspects related with the study sample and the nature of the assessment rubrics and instruments that must be kept in mind. Firstly, concerning the study sample, whereas UJr's participants had just finished the 10th and 11th grades, the students who participated in the school activity were 12th graders. Therefore, it is possible that these students' knowledge about the issues discussed differed. According to the Portuguese biology programs for these instructional levels, contents related to cell structure and uni-/multicellularity, taxonomy and classification systems, and antibiotics are to be addressed respectively at the 10th, 11th, and 12th grades (DEB, 2001; DGIDC, 2001, 2003, 2004). In spite of this, it is worth noting that the activity was introduced in schools by the time the 12th graders began addressing antibiotic production-related contents and therefore there was a narrow chance that their baseline knowledge (i.e. measured in the pre-test) deriving from their formal education, was higher than that of their younger counterparts. Indeed, from the pre-test data (Chapter 6), the notions conveyed by the students in both cases, were overall similar, and there was no observed tendency for one group to outperform the other. This leads to the second aspect to acknowledge, which relates to the nature of the assessment conducted. Even though a pre-/post-design was used in both situations, the measurement instruments were not the same, which prevents making direct comparisons. In line with this, the aspects discussed must be interpreted as tendencies.

The analysis of the pre-/post-test data reveals that the activity contributed to improving students' knowledge and understanding in both contexts (Chapter 6). In addition, the feedback gathered indicates that the students were actively engaged in the activity and that it contributed to increase their interest and curiosity about the topic addressed. Nevertheless, in face of the characteristics of the two validation settings explored, which necessarily mediate the effectiveness of the activity in each case, it is important to consider the influence of the formal or informal character of the context and the students' enrolment.

One of the most significant factors associated with educational contexts is the motivational elements that are at stake (Bell, 2009). Motivation, and interest specifically, can be conceptualised according to different criteria (Deci, 1992; Krapp, Hidi, & Renninger, 1992; Rotgans & Schmidt, 2011; Ryan & Deci, 2000; Schiefele, 2009. The model previously introduced by Ryan and Deci (2000) proposes that motivational responses are determined by extrinsic and intrinsic dimensions, the latter corresponding to what is broadly understood as interest. In turn, interest can be categorised in various sub-dimensions, the most relevant of which, for the purpose of this project, are individual or personal, and situational interest (Ainley & Ainley, 2001; Krapp et al., 1992; Schiefele, 2009). While all of these dimensions expectably contributed to shape the motivational responses of the UJr participants and in the classroom, their relative impact levels may have varied from one context to the other.

Given that UJr participants personally enrolled in the project, while the classroom activity was presented to the 12th grade students as part of their typical biology class agenda, it is possible that the first students nurtured a higher level of personal interest towards the topic and the activity itself. Nevertheless, this assumption is not straightforward, since the 12th grade students could have been also naturally interested in antibiotic use and resistance, and UJr participants may have different motivations to enrol in the projects available. For instance, the feedback provided by some UJr participants, who found the amount of theory provided to be excessive and proposed even more social interaction (Chapter 6), suggests that they were expecting more entertaining scenarios. It is possible that, in this case, their motivation stemmed from anticipated social interactions, and fell shorter on the side of the learning opportunities fostered (Packer & Ballantyne, 2004; Rudduck & McIntyre, 2007; Toplis, 2011).

Studies focusing on students' interest have shown that interest in a given subject can be prompted by situational variables associated with the environment in which an educational activity takes place (Abrahams & Millar, 2009; Krapp & Prenzel, 2011). In both the formal and informal context, and consistently with reports on several studies (Holstermann et al., 2010; Toplis, 2011), the opportunity to manipulate laboratory material and equipment was highlighted by the students as an especially appealing aspect (Chapter 6). Hence, this was probably a major stimulus triggering their intrinsic motivation.

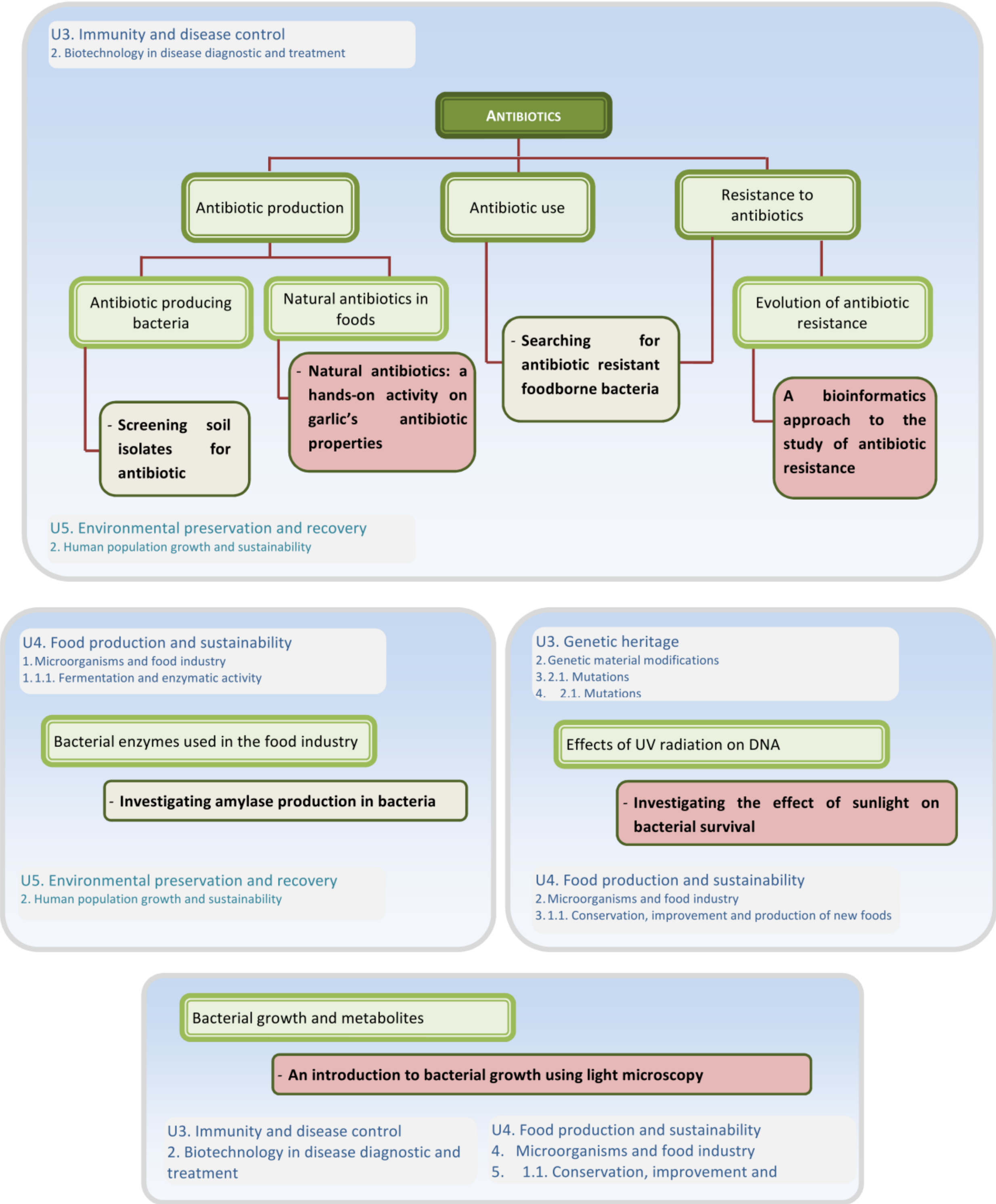

Fig. VII.1. Examples of activities designed in the course of the project.
The activities highlighted were trialed and tested. *Natural antibiotics: a hands-on activity on garlic's antibiotic properties* and *A bioinformatics approach to the study of antibiotic resistance* were implemented in formal (high school biology classes) and informal (UJr) contexts. *Investigating the effect of sunlight on bacterial survival* was implemented in a formal high school context. *An introduction to bacterial growth using light microscopy* was implemented in an informal context (UJr).

In addition to interest, the role of extrinsic motivational factors must also be considered. The activity addressed a significant public health issue, which the students perceived as important (Chapter 6). This may have contributed to motivate them in engaging in the activity. Furthermore, the need to be successful in their academic duties and accomplish curricular demands could have been an important exogenous motivational factor (Deci, 1992), especially for the 12th grade biology students, whose performance was being graded.

Finally, in what concerns the impact of all these motivational elements on students' learning and future relationship with science, it should be considered that the motivation registered does not warrant enduring personal interest in these topics (Abrahams & Millar, 2009; Krapp & Prenzel, 2011). The UJr project and the classroom activities may have been effective in raising the participants' situational interest about antibiotic use and resistance without affecting their future relationship with science, namely regarding the pursuit of a science career. Assuming that the participants' learning gains were associated with the interplay of various motivational elements, and that the influence of situational interest and extrinsic motivation can prevail over personal interest in classroom instruction (Deci, 1992); the possibility that the engagement and learning experienced by the students were transient cannot be ruled out. Regardless of the invaluable benefits of promoting young people's long-term interest in science, the purpose of these activities was to stimulate the participants' short-term engagement with the contents and procedures to foster meaningful learning and increase awareness towards antibiotic resistance. In this scope, the data gathered point towards the effectiveness of the activity.

Mixing and matching: the unavoidable need for alignment in science education research and assessment

This project had very well-defined objectives and research questions, which demanded a purposeful selection of both quantitative and qualitative research methods. The main concern when devising the research methodology was to ensure alignment between the goals, the assessment and the expected results, in light of the theoretical framework defined, and considering the validity and reliability of the data collected. This was in line with the acknowledgement that research set ups must allow the triangulation of results and the comparison of data from different studies (Onwuebuzie & Mallete, 2011). Therefore, having in mind the purpose of each of the tasks defined to attain the main goals of the project, the research unfolded along a multi-step strategy based upon a quasi-experimental design, relying on quantitative-driven methodology, followed by a mix-method approach.

For the diagnostic assessment of students' perceptions about biotechnology and teachers' beliefs about biotechnology and biotechnology education, a quantitative methodology was selected (Chapters 3 and 4). The goal was to obtain a broad characterisation of how the populations sampled viewed these issues and felt about them, which called for this type of methods (Black, 1999; Cohen, Manion, & Morrison, 2007). To improve the quality of the data gathered, aiming to allow generalisation and extrapolation, the surveys developed were validated following the procedures described in Chapters 2 and 3. The validation procedures were found to be essential to understand the psychometric properties of the instruments developed, and particularly, to present a sound specification and elaboration of the constructs to be measured, which seems almost intuitive. Nevertheless, as mentioned in Chapter 2.2, although validation is an unavoidable step in science education and social sciences research, there are numerous studies in which the procedures are overlooked or at least not reported (Blalock et al., 2008). In this context, the guidelines made available in Chapter 2.2, present a contribution to raise awareness and assist researchers who are not experienced with statistical validation techniques to examine their data according to a commonly used procedure in quantitative research, i.e. exploratory factor analysis and reliability analysis. The approach proposed does not dismiss the suitability of other methods depending on the research agenda and goals.

The validation of the activity developed in formal and informal settings was carried out following a mix-method approach. Mix-method research refers to the type of research in which quantitative and qualitative methods are combined, and the outcomes of their implementation are combined to achieve broader, deeper and more rigorous understanding, and corroborate results (Johnson, Onwuegbuzie, & Turner, 2007). Although this sort of evaluation strategy has spawned some debate among social science researchers, who often share contrasting views about the rigor and transferability of the findings obtained from it, a manifested usefulness exists in incorporating different methods in a research study. The procedure allows to generate data from various sources, to boost the generalizability of the findings, and to multiply the research phases to better address a research objective (Creswell, 2003; Creswell & Clark, 2010). In this work, the mix-method approach was intended to gather the maximum amount of information that could provide a comprehensive perusal of the activity's impact on the participants' understanding and awareness. Indeed, this approach produced a wealth of information that bares significant implications for the design of practical activities, as discussed in Chapter 6, and that enables the implementation of the activity and others alike in different environments.

The combination of qualitative and quantitative data also allowed the clarification of the interpretation of the findings, as shown by the following example. The pre-/post-tests used in the validation of the activity (Chapter 6), included open-ended questions, given that it was aimed to assess variations in the quality of the students' responses. These questions, although possibly giving room to more subjective interpretations than closed questions, are much more informative of the respondents' knowledge, understanding, or opinion, as they give them freedom to convey whichever notions they wish without influencing their answers with a set of predefined options, Oppenheim, 1992). To address this issue, a thorough content analysis was performed (Chapter 6), allowing to quantify the correct and incorrect notions provided by the students prior and after their participation in the activity. These notions were then cross-examined using statistical indicators. This quantitative evaluation of the students' responses allowed for a reliable assessment of the effectiveness of their learning.

It is also important to mention that the association of self-reported, observed and other indirectly collected data, in which the assessment strategy relied, proved to be an efficient methodological option. Given the common discrepancy between what people say and think that they learned and what was actually learned (Cohen et al., 2007; Oppenheim, 1992), the integration of these types of information provides a more realistic picture of the learning that takes place.

Future Perspectives

The work presented and discussed in this thesis was framed within a specific timeline, which demanded following a well-defined line of reasoning, so as not to swerve from the focus of the research carried out and the main goals set. Nevertheless, I believe that the impact of this project may extend the limits of this dissertation. The work developed allowed to answer the questions posed at the beginning of the project and others that came up along its course, which in itself is of relevance for researchers and practitioners. Yet, and arguably most importantly, this project raised several questions that are worth pursuing in future research.

- **Cross-comparison between students' and teachers' perceptions about biotechnology and biotechnology education**

  With the purpose of gathering indicators to purposely design meaningful educational activities for implementation in formal and informal instructional settings, this project included the characterisation of elementary and high school students' perceptions about biotechnology (Chapter 3), and biology teachers' beliefs about biotechnology and biotechnology education (Chapter 4). The data gathered were combined in order to efficiently attend to both the students' and the teachers' needs. However, considering the influential role that teachers play in shaping students' opinions and behaviour, it would be interesting to compare their perceptions and beliefs directly. Similarly to what was done in the course of this project for the students' and teachers' use of and trust in information sources, it would be particularly important to cross-compare their views on the curricular coverage of biotechnology and on their experience in engaging with biotechnology education. This would allow bridging the current gap in research on this link (Kidman, 2010), as well as contribute to enhancing the efficacy of science instruction by improving the quality of science curricula.

- **Going further and wider: extending the scope of the project to other, diversified, populations**

Extending the scope of this project at all levels, from the multidimensional analysis of students' perceptions to the development of the project *Microbiology recipes: antibiotics à la carte*, to populations from different backgrounds and socio-demographic profiles, would strengthen the evidence gathered and contribute to the generalizability of the findings.

Furthermore, there is a wide diversity of factors that vary across countries, such as Australia, the USA, Slovenia, Turkey, or the UK which have demonstrated institutional concerns with the promotion of biotechnology education at elementary school and high school levels (France, 2003; Hanegan & Bigler, 2009; Šorgo & Ambrožič-Dolinšek, 2009; Steele & Aubusson, 2004; Uşak et al., 2009). It would be interesting to investigate the impact of features such as culture, gender, language, or ethnicity, among others, at national and international scales in these countries. It would also be important to consider countries with different legislative and regulation policies concerning biotechnology applications and products, as this can influence the effectiveness of school science instruction.

- **Validation of further laboratory activities**

The main purpose of this project was to assess the impact of innovative laboratory activities on students' understanding and perceptions about biotechnology-related issues. To achieve this goal, the outcomes of the diagnostic assessment of students and teachers perceptions and beliefs were examined, seeking to identify which contents should be preferably addressed and how to do it in order to harmoniously meet both the students' and the teachers' needs and concerns. Future research drawing on this project could be carried out to validate the other activities devised (Fig. VII.1).

- **Development of teacher training workshops on biotechnology education activities**

  The investment in teacher training, both in pre-service and in inservice education, is an essential requirement for the effectiveness of science education. Considering the challenges present by such a fast-growing area of research as biotechnology, providing teachers with the tools required for the successful implementation of biotechnology education initiatives in schools is of pivotal importance. Based on the insightful perspective provided by the findings of the teachers' diagnostic assessment (Chapter 4), a particularly relevant area for intervention relates to the improvement of teachers' information literacy skills. Consistently with what previous studies have admonished (Sundin & Francke, 2009; Wan & Gut, 2009; Sun & Liu, 2009; Julien & Barker, 2009), these findings sustain that teachers tend to rely on a small number of information sources that may not be particularly reliable, and their awareness of available educational resources is limited. Teachers were receptive to attending workshops on this topic. Therefore, it would be useful to organise continuing teacher training programs intended at promoting teachers' competencies in searching and adapting information and resources about biotechnology to their specific context. To monitor the impact of these courses, it would be important to ensure a follow up of whether and how the teachers actually took their improved skills into the classroom and applied them in their practice.

- **Assessment of the effectiveness of specific social groups' engagement in the promotion of biotechnology education**

  Despite the major role that teachers play on education, students are inevitably also influenced by the social and cultural inputs from society-based information (Bonfadelli, 2005; Braun & Moses, 2004). It is generally agreed that scientific literacy cannot be achieved unless an interconnection is established between the subjects taught in schools and the social environment surrounding the students outside the classroom (Barron 2006; Bennet et al., 2007; Hagay & Baram-Tsabari, 2010; McClune & Jarman, 2010). The accuracy of the information transmitted by the media, universities, health, food, and environmental organisations, journalists and politicians, among others, is unquestionably a key factor influencing citizen's capacity to weigh the risks and benefits of science-applications, in order to make informed decisions (McClune & Jarman, 2010; Vilella-Vila, Costa-Font, & Mossialos, 2005). Therefore, consistently with an externalist perspective of science education, the findings obtained could be complemented with evaluation of the influence of outside school professional groups in the promotion of students' scientific literacy regarding biotechnology.

References

Abrahams, I. (2009). Does practical work really motivate? A study of the affective value of practical work in secondary school science. *International Journal of Science Education, 31*(17), 2335-2353.

Abrahams, I., & Millar, R. (2008). Does practical work really work? A study of the effectiveness of practical work as a teaching and learning method in school science. *International Journal of Science Education, 30*(14), 1945-1969.

Abrahams, I., & Saglam, M. (2009). A Study of teachers' views on practical work in secondary schools in England and Wales. *International Journal of Science Education, 32*(6), 753-768.

Ainley, M., & Ainley, J. (2011). A Cultural perspective on the structure of student interest in science. *International Journal of Science Education, 33*(1), 51-71.

Allen, E. E., & Hood, L. (2000). Biotechnology, inquiry, and public education. *Trends in Biotechnology, 18*(8), 329-330.

Amin, L., Jahi, J., Nor, A. R., Osman, M., & Mahadi, N. M. (2007). Public acceptance of modern biotechnology *Asia Pacific Journal of Molecular Biology and Biotechnology, 15*(2), 39-51.

Baram-Tsabari, A., & Yarden, A. (2009). Identifying meta-clusters of students' interest in science and their change with age. *Journal of Research in Science Teaching, 46*(9), 999-1022.

Barron, B. (2006). Interest and self-sustained learning as catalysts of development: A learning ecology perspective. *Human Development, 49*(4), 193-224.

Bell, P. (Ed.). (2009). *Learning science in informal environments: People, places, and pursuits*. Washington, DC: National Academies Press.

Bennett, J., Lubben, F., & Hogarth, S. (2007). Bringing science to life: A synthesis of the research evidence on the effects of context-based and STS approaches to science teaching. *Science Education, 91*(3), 347-370.

Beyer, C. J., & Davis, E. A. (2012). Learning to critique and adapt science curriculum materials: Examining the development of preservice elementary teachers' pedagogical content knowledge. *Science Education, 96*(1), 130-157.

Black, T. R. (1999). *Doing quantitative research in the Social Sciences. An integrated approach to research design, measurement and statistics*. London: SAGE Publications.

Blalock, C. L., Lichtenstein, M. J., Owen, S., Pruski, L., Marshall, C., & Toepperwein, M. (2008). In pursuit of validity: A comprehensive review of science attitude instruments 1935–2005. *International Journal of Science Education, 30*(7), 961-977.

Bonfadelli, H. (2005). Mass media and biotechnology: Knowledge gaps within and between European countries. *International Journal of Public Opinion Research, 17*(1), 42-62.

Branch, J. L. (2003). Instructional intervention is the key: Supporting adolescent information seeking. *School Libraries Worldwide, 9*(2), 47-61.

Bransford, J. (Ed.). (2000). *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academy Press.

Bransford, J. D., & Donovan, M. S. (2005). Scientific inquiry and how people learn. In S. Donovan & J. Bransford (Eds.), *How students learn: History in the classroom* (pp. 397-420). Washington, DC: National Academies Press.

Braun, R., & Moses, V. (2004). A public policy on biotechnology education: what might be relevant and effective? *Current Opinion in Biotechnology, 15*(3), 246-249.

Braund, M., & Reiss, M. (2006). Validity and worth in the science curriculum: learning school science outside the laboratory. *Curriculum Journal, 17*(3), 213 - 228.

Brossard, D., & Nisbet, M. C. (2007). Deference to scientific authority among a low information public: Understanding U.S. opinion on agricultural biotechnology. *International Journal of Public Opinion Research, 19*(1), 24-52.

Bryce, T., & Gray, D. (2004). Tough acts to follow: the challenges to science teachers presented by biotechnological progress. *International Journal of Science Education, 26*, 717-733.

Calley, N. G. (2010). *Program development in the 21st century: An evidence-based approach to design, implementation, and evaluation*. Thousand Oaks, CA: Sage Publications.

Cerini, B., Murray, I., & Reiss, M. (2003). *Student review of the science curriculum. Major findings.* London: Planet Science/Institute of Education University of London/Science Museum. Retrieved from http://www.planet-science.com/sciteach/review.

Cochran-Smith, M., Feiman-Nemser, S., & McIntyre, D. J. (2008). *Handbook of research on teacher education: Enduring questions in changing contexts*. Abingdon, Oxon: Routledge.

Cohen, L., Manion, L., & Morrison, K. (2007). *Research methods in education* (6th ed.). London; New York: Routledge Falmer.

Concannon, J., Siegel, M., Halverson, K., & Freyermuth, S. (2010). College students' conceptions of stem cells, stem cell research, and cloning. *Journal of Science Education and Technology, 19*(2), 177-186.

Costa, M. J. (2007). Blackboard electrophoresis. *Biochemistry and Molecular Biology Education, 35*(5), 328-331.

Creswell, J. W. (2003). *Research design: Qualitative, quantitative, and mixed method approaches*. Thousand Oaks, CA: Sage Publications.

Creswell, J. W., & Clark, V. L. P. (2010). *Designing and conducting mixed methods research*. Thousand Oaks, CA: SAGE Publications.

Cuevas, P., Lee, O., Hart, J., & Deaktor, R. (2005). Improving science inquiry with elementary students of diverse backgrounds. *Journal of Research in Science Teaching, 42*(3), 337-357.

Dagenais, D., Moore, D., & Sabat, C. (2009). Negotiating teacher-researcher collaboration in immersion education. In J. Miller, A. Kostogriz & M. Gearon (Eds.), *Culturally and Linguistically Diverse Classrooms: New Dilemmas for Teachers* (pp. 234-251). Bristol, New York, Ontario: Multilingual Matters.

Dawson, V. (2007). An exploration of high school (12–17 year old) students' understandings of, and attitudes towards biotechnology processes. *Research in Science Education, 37*(1), 59-73.

Deci, E. L. (1992). The relation of interest to the motivation of behavior: a self-determination theory perspective. In K. A. Renninger, S. Hidi & A. Krapp (Eds.), *The Role of interest in learning and development* (pp. 43-70). Hillslade, NJ: L. Erlbaum Associates.

Departamento de Educação Básica. (2001). *Orientações curriculares do ensino básico - ciências físicas e naturais.* Lisboa: Ministério da Educação.

Direcção Geral de Inovação e de Desenvolvimento Curricular (2001) Programa de biologia e geologia 10º ou 11º anos. Lisboa, Portugal: Ministério da Educação.

Direcção Geral de Inovação e de Desenvolvimento Curricular (2003) Programa de biologia e geologia 11º ou 12º anos. Curso científico-humanístico de ciências e tecnologias. Lisboa, Portugal: Ministério da Educação.

Direcção-Geral de Inovação e de Desenvolvimento Curricular. (2004). *Programa de Biologia 12º ano. Curso Científico - Humanístico de Ciências e Tecnologias.* Lisboa: Ministério da Educação.

Dori, Y. J., Tal, R. T., & Tsaushu, M. (2003). Teaching biotechnology through case studies - can we improve higher order thinking skills of nonscience majors? *Science Education, 87*(6), 767-793.

Doyle, C. S. (1994). *Information literacy in an information society: a concept for the information age*. Syracuse, New York: ERIC Clearinghouse on Information & Technology.

Drechsel, B., Carstensen, C., & Prenzel, M. (2011). The role of content and context in PISA interest scales: A study of the embedded interest items in the PISA 2006 science assessment. *International Journal of Science Education, 33*(1), 73-95.

Eisenkraft, A., & Anthes-Washburn, M. (2008). Assessment of laboratory investigations. In J. Coffey, R. Douglas & C. Stearns (Eds.), *Assessing science learning: perspectives from research and practice* (pp. 145-165). Arlington VA: NSTA Press.

Elliott, P. (2006). Reviewing newspaper articles as a technique for enhancing the scientific literacy of student-teachers. *International Journal of Science Education, 28*(11), 1245-1265.

Falk, H., Brill, G., & Yarden, A. (2008). Teaching a biotechnology curriculum based on adapted primary literature. *International Journal of Science Education, 30*(14), 1841-1866

Fenichel, M., & Schweingruber, H. A. (2010). *Surrounded by science: Learning science in informal environments*. Washington, DC: National Academies Press.

Fitzsimons, P. (2007). Biotechnology, ethics and education. *Studies in Philosophy and Education, 26*(1), 1-11. doi: 10.1007/s11217-006-9011-5

Fonseca, M. J., Costa, P., Lencastre, L., & Tavares, F. (2011, August). Use of information sources about socio-scientific issues in elementary school and high school. Communication presented at the *14th European Association for Research on Learning and Instruction* (EARLI) Conference in Exeter, UK (http://www.earli2011.org/nqcontent.cfm?a_id=1).

France, B. (2003). GE Free: Rejection or Incomprehension? The challenge for New Zealand biotechnology education. *Canadian Journal of Science, Mathematics and Technology Education, 3*(1), 145-156.

France, B. (2007). Location, Location, Location: Positioning biotechnology education for the 21st century. *Studies in Science Education, 43*(1), 88-122.

Gardner, G., & Jones, M. (2010). science instructors' perceptions of the risks of biotechnology: implications for science education. *Research in Science Education*, 1-28.

Gaskell, G., Stares, S., Allansdottir, A., Allum, N., Corchero, C., Fischler, C., …Wagner, W. (2006). Europeans and biotechnology in 2005: Patterns and trends. Final report on Eurobarometer 64.3. Brussels: European Commission, Research Directorate-General.

Grubb, W. N., & Cox, R., D. (2005). Pedagogical alignment and curricular consistency: The challenges for developmental education. *New Directions for Community Colleges, 2005*(129), 93-103.

Hagay, G., & Baram-Tsabari, A. (2010). A shadow curriculum: incorporating students' interests into the formal biology curriculum. *Research in Science Education*, 1-24.

Haigh, M. (1993). "Hands on-minds on": Introducing openness into senior biology practical work. *Research in Science Education, 23*(1), 110-117.

Halverson, K. L., Siegel, M. A., & Freyermuth, S. K. (2010). Non-science majors' critical evaluation of websites in a biotechnology course. *Journal of Science Education and Technology, 19*(6), 612-620.

Hanegan, N., & Bigler, A. (2009). Infusing authentic inquiry into biotechnology. *Journal of Science Education and Technology, 18*(5), 393-401.

Henson, R. K., & Roberts, J. K. (2006). Use of exploratory factor analysis in published research. Common errors and some comment on improved practice. *Educational and Psychological Measurement, 66*(3), 393-416

Ho, S. S., Brossard, D., & Scheufele, D. A. (2008). Effects of value predispositions, mass media use, and knowledge on public attitudes toward embryonic stem cell research. *International Journal of Public Opinion Research, 20*(2), 171-192.

Hofstein, A., Eilks, I., & Bybee, R. (2011). Societal issues and their importance for contemporary science education - A pedagogical justification and the state-of-the-art in Israel, Germany, and the USA. *International Journal of Science and Mathematics Education, 9*(6), 1459-1483.

Hofstein, A., & Lunetta, V. N. (2003). The laboratory in science education: foundations for the twenty-first century. *Science Education, 88*(1), 28-54.

Holstermann, N., Grube, D., & Bögeholz, S. (2010). Hands-on activities and their influence on students' interest. *Research in Science Education, 40*(5), 743-757.

House of Commons Science and Technology, & Committee. (2002). *Third report. Science education from 14 to 19.* London: HMSO Retrieved from http://www.publicationsparliament.uk/pa/cm200102/cmselect/cmsctech/508/50802.htm.

Hume, A., & Coll, R. (2008). Student experiences of carrying out a practical science investigation under direction. *International Journal of Science Education, 30*(9), 1201-1228.

Johnson, R. B., Onwuegbuzie, A. J., & Turner, L. A. (2007). Toward a definition of mixed methods research. *Journal of Mixed Methods Research, 1*(2), 112-133.

Julien, H., & Barker, S. (2009). How high-school students find and evaluate scientific information: A basis for information literacy skills development. *Library & Information Science Research, 31*(1), 12-17.

Kerfeld, C. A., Levis, M., & Perry, L. J. (2001). Teaching and exploring the social implications of twenty-first century molecular biology in a laboratory-based general education course. *Innovative Higher Education, 26*(2), 87-102.

Kidman, G. (2008). Asking students: What key ideas would make classroom biology interesting? *Teaching Science, 54*(2), 34-38.

Kidman, G. (2010). What is an 'interesting curriculum' for biotechnology education? Students and teachers opposing views. *Research in Science Education, 40*(3), 353-373.

Klop, T., & Severiens, S. (2007). An exploration of attitudes towards modern biotechnology: A study among Dutch secondary school students. *International Journal of Science Education, 29*(5), 663-679.

Knobloch, N. A. (2006). Exploring relationships of teachers' sense of efficacy in two student teaching programs. *Journal of Agricultural Education, 47*(2), 36-47.

Koba, S., & Tweed, A. (2009). *Hard-to-teach biology concepts: A framework to deepen student understanding*. Arlington VA: NSTA Press.

Krapp, A., Hidi, S., & Renninger, K. A. (1992). Interest, learning and development. In K. A. Renninger, S. Hidi & K. , A. (Eds.), *The role of interest in learning and development.* (pp. 3-26). Hillslade, NJ: L. Erlbaum Associates.

Krapp A, & Prenzel M (2011) Research on interest in science: Theories, methods, and findings. *International Journal of Science Education*, *33*(1), 27-50.

Kyriakides, L., & Kelly, K. L. (2003). The impact of engagement in large-scale assessment on teachers' professional development: the emergent literacy baseline assessment project. *Journal of Research in Childhood Education, 18*(1), 18-36.

Lamanauskas, V., & Makarskaitė-Petkevičienė, R. (2008). Lithuanian university students' knowledge of biotechnology and their attitudes to the taught subject. *Eurasia Journal of Mathematics, Science & Technology Education, 4*(3), 269-277.

Lawson, M. A. (2008). The antibiotic resistance problem revisited. *American Biology Teacher, 70*(7), 405-410.

Lewis, J., & Kattmann, U. (2004). Traits, genes, particles and information: re-visiting students' understandings of genetics. *International Journal of Science Education, 26*(2), 195-206.

Lindahl, B. (2003). Pupils' responses to school science and technology? A longitudinal study of pathways to upper secondary school. *Gőteborg: Acta Universitatis Gothoburgensis*.

Maniotes, L. K., Caspari, A. K., & Kuhlthau, C. C. (2007). *Guided inquiry learning in the 21st century*. Westport, CT: Libraries Unlimited.

McClune, B., & Jarman, R. (2010). From aspiration to action: A learning intentions model to promote critical engagement with science in the print-based media. *Research in Science Education*, 1-20.

Mohrig, J. R. (2004). The problem with organic chemistry labs. *Journal of Chemical Education, 81*(8), 1083.

National Association of Biology Teachers. (2005). *Role of laboratory and field instruction in biology education.*: Retrieved from http://www.nabt.org/sites/S1/index.php?p=67.

National Research Council. (1996). *National science education standards*. Washington, DC: National Academy Press.

Onwuebuzie, A. J., & Mallete, M. H. (2011). Mixed research techniques in literacy research. In N. K. Duke & M. H. Mallette (Eds.), *Literacy research methodologies* (2nd ed.) (pp. 301-330). New York: Guilford Publications.

Oppenheim, A. N. (1992). *Questionnaire design, interviewing and attitude measurement* (New ed.). London; New York: Continuum.

Osborne, J. (1998). Science education without a laboratory. In J. Wellington (Ed.), *Practical work in school science: Which way now?* (pp. 156-173). London: Routledge.

Osborne, J., & Collins, S. (2000). *Pupils' and parents' views of the school science curriculum* London: Kings College London.

Ottander, C., & Grelsson, G. (2006). Laboratory work: the teachers' perspective. *Journal of Biological Education, 40*(3), 113-118.

Packer J, & Ballantyne R (2004) Is educational leisure a contradiction in terms? Exploring the synergy of education and entertainment. *Annals of Leisure Research, 7*(1), 54-71.

Persico, D., & Manca, S. (2000). Use of FirstClass as a collaborative learning environment. *Innovations in Education & Training International, 37*(1), 34-41.

Phillips, A. R., Robertson, A. L., Batzli, J., Harris, M., & Miller, S. (2008). Aligning goals, assessments, and activities: An approach to teaching PCR and gel electrophoresis. *CBE-Life Sciences Education, 7*(1), 96-106.

Pintrich, P. R. (2003). A motivational science perspective on the role of student motivation in learning and teaching contexts. *Journal of Educational Psychology, 95*(4), 667-686.

Pouliot, C. (2010). Post-secondary students' relationship to people they consider to be scientific experts. *Research in Science Education*, 1-19.

Prokop, P., Lesková, A., Kubiatko, M., & Diran, C. (2007). Slovakian students' knowledge of and attitudes toward biotechnology. *International Journal of Science Education, 29*(7), 895-907.

Ramón, D., Diamante, A., & Calvo, M. D. (2008). Food biotechnology and education. *Electronic Journal of Biotechnology, 11*(5). Retrieved from: http://www.scielo.cl/scielo.php?pid=S0717-34582008000500001&script=sci_arttext.

Rotgans, J. I., & Schmidt, H. G. (2011). The role of teachers in facilitating situational interest in an active-learning classroom. *Teaching and Teacher Education, 27*(1), 37-42.

Rudduck J, & McIntyre D (2007) Improving learning through consulting pupils. New York: Routledge.

Ryan, R. M., & Deci, E. L. (2000). Intrinsic and extrinsic motivations: Classic definitions and new directions. *Contemporary Educational Psychology, 25*(1), 54-67.

Sáez, M. J., Niño, A. G., & Carretero, A. (2008). Matching society values: students' views of biotechnology. *International Journal of Science Education, 30*(2), 167-183.

Sagar, A., Daemmrich, A., & Ashiya, M. (2000). The tragedy of the commoners: biotechnology and its publics. *Nature Biotechnology, 18*(1), 2-4.

Savadori, L., Savio, S., Nicotra, E., Rumiati, R., Finucane, M., & Slovic, P. (2004). Expert and public perception of risk from biotechnology. *Risk Analysis, 24*, 1289-1299.

Scharfenberg, F.-J., & Bogner, F. (2010). A new two-step approach for hands-on teaching of gene technology: effects on students' activities during experimentation in an outreach gene technology lab. *Research in Science Education*, *41*(4), 505-523.

Schiefele, U. (2009). Situational and individual interest. In K. R. Wentzel & A. Wigfield (Eds.), *Handbook of motivation at school* (pp. 197-223). New York: Routledge.

Shaw, K. R. M., Van Horne, K., Zhang, H., & Boughman, J. (2008). Essay contest reveals misconceptions of high school students in genetics content. *Genetics, 178*(3), 1157-1168.

Shimabukuro, M. A., & Haberman, V. (2006). An aromatic adventure with allelopathy: Using garlic to study allelopathy in the classroom. *American Biology Teacher, 68*(4), 242-247.

Siegrist, M. (2000). The influence of trust and perceptions of risks and benefits on the acceptance of gene technology. *Risk Analysis, 20*(2), 195-204.

Siti Hendon, S. A., & Khalijah, M. S. (2007). Science teaching for enlightment: a holistic approach in developing a teachers' guide for best practices to teach at secondary level. *Asia-Pacific Forum on Science Learning and Teaching, 8*(1).

Smithenry, D. W. (2010). Integrating guided inquiry into a traditional chemistry curricular framework. *International Journal of Science Education*, *32*(13), 1689-1714.

Spector, B., & Yager, R. (2010). The many faces of STS. Social issues in science education. In S. Totten & J. E. Pedersen (Eds.), *Teaching and Studying Social Issues: Major Programs and Approaches* (pp. 277-312). Charlette, NC: Information Age Publishing.

Sorgo, A., & Ambrozic-Dolinsek, J. (2010). Knowledge of, attitudes toward, and acceptance of genetically modified organisms among prospective teachers of biology, home economics, and grade school in Slovenia. *Biochemistry and Molecular Biology Education, 38*(3), 141-150.

Steele, F., & Aubusson, P. (2004). The challenge in teaching biotechnology. *Research in Science Education, 34*, 365-387.

Sturgis, P., Cooper, H., & Fife-Schaw, C. (2005). Attitudes to biotechnology: Estimating the opinions of a better-informed public. *New Genetics & Society, 24*(1), 31-56.

Sun, H., & Liu, T. (2009). Cultivation of science teachers' information literacy in China. *International Education Studies, 2*(3), 147-150.

Sundin, O., & Francke, H. (2009). In search of credibility: Pupils' information practices in learning environments. *Information Research: An International Electronic Journal, 14*(4). Retrieved from http://informationr.net/ir/14-4/paper418.html.

Tibell, L. A. E., & Rundgren, C.-J. (2010). Educational challenges of molecular life science: characteristics and implications for education and research. *CBE-Life Sciences Education, 9*(1), 25-33. doi: 10.1187/cbe.08-09-0055

Topcu, M. S., Sadler, T. D., & Yilmaz-Tuzun, O. (2010). Preservice science teachers' informal reasoning about socioscientific issues: The influence of issue context. *International Journal of Science Education, 32*(18), 2475-2495.

Toplis, R. (2012). Students' Views About Secondary School Science Lessons: The Role of Practical Work. *Research in Science Education, 42*(3), 531-549.

Uşak, M., Erdogan, M., Prokop, P., & Özel, M. (2009). High school and university students' knowledge and attitudes regarding biotechnology. *Biochemistry and Molecular Biology Education, 37*(2), 123-130.

van Mil, M. H., Boerwinkel, D. J., Buizer-Voskamp, J. E., Speksnijder, A., & Waarlo, A. J. (2010). Genomics education in practice: Evaluation of a mobile lab design. *Biochemistry and Molecular Biology Education, 38*(4), 224-229.

Vilella-Vila, M., Costa-Font, J., & Mossialos, E. (2005). Consumer involvement and acceptance of biotechnology in the European Union: a specific focus on Spain and the UK. *International Journal of Consumer Studies, 29*, 108-118.

Wan, G. F., & Gut, D. M. (2008). Media use by Chinese and US secondary students: Implications for media literacy education. *Theory into Practice, 47*(3), 178-+.

Ward, H., & Hockey, J. (2007). Engaging the learner: Embedding information literacy skills into a biotechnology degree. *Biochemistry and Molecular Biology Education, 35*(5), 374-380.

Ware, M. E., & Johnson, D. E. (2000). *Handbook of Demonstrations and Activities in the Teaching of Psychology: Personality, abnormal, clinical-counseling, and social*. Mahwah, NJ: Lawrence Erlbaum Associates.

Wassmer, G. T., Kipe-Nolt, J. A., & Chayko, C. A. (2006). Why finish your antibiotics? A novel, hands-on, classroom approach for teaching the dynamics of antibiotic resistance. *American Biology Teacher, 68*(8), 476-480.

William A., & Sandoval, B. J. R. (2004). Explanation-driven inquiry: Integrating conceptual and epistemic scaffolds for scientific inquiry. *Science Education, 88*(3), 345-372.

Williams, D., & Coles, L. (2007). Teachers' approaches to finding and using research evidence: an information literacy perspective. *Educational Research, 49*(2), 185-206.

Wragg, E. C., Wikeley, F. J., Wragg, C. M., & Haynes, G. S. (1996). *Teacher Appraisal Observed*. London: Routledge.

Yen, H.-C., Tuan, H.-L., & Liao, C.-H. (2010). Investigating the Influence of Motivation on Students' Conceptual Learning Outcomes in Web-based vs. Classroom-based Science Teaching Contexts. *Research in Science Education*, *41*(2), 211-224.

APPENDICES

APRECIAÇÃO GLOBAL DAS ACTIVIDADES

Guião de entrevista aos alunos

1- *Lembram-se das actividades?*
2- *As actividades foram semelhantes às que estão habituados?*
3- *Quais foram os aspectos que <u>mais</u> e <u>menos</u> gostaram?*
4- *Houve algum aspecto que vos tenha surpreendido?*
5- *E como lidaram com os resultados inesperados, nomeadamente ao nível das actividades dos UV?*
   5.1. E se vos acontecesse num laboratório de investigação?
6- *O desempenho do(a) vosso(a) Professor(a) foi idêntico ao habitual? Ou notaram alguma diferença?*
7- *Qual a <u>utilidade</u> e <u>interesse</u> das actividades? Agora, num contexto académico, e no vosso futuro, como cidadãos?*
8- *De qual dos temas gostaram mais?*
9- *O que pensam da estrutura das actividades (componente teórica e prática)? E especificamente da prática de bioinformática?*
10- *O que pensam da duração das actividades?*
11- *Acham que as actividades foram muito difíceis? A parte teórica (nomeadamente por estar em Inglês) e a parte prática (com os procedimentos propostos)?*
12- *Indiquem os principais aspectos <u>negativos</u> e <u>positivos</u> das actividades.*
13- *Apresentem algumas sugestões para melhorar as actividades.*
14- *Quais as principais dificuldades que tiveram ao responder aos questionários?*

U.PORTO FC FACULDADE DE CIÊNCIAS UNIVERSIDADE DO PORTO

IBMC INSTITUTO DE BIOLOGIA MOLECULAR E CELULAR INSTITUTE FOR MOLECULAR AND CELL BIOLOGY

APRECIAÇÃO GLOBAL DA ACTIVIDADE

Nome: ____

Data: ___/___/___

1. Idade: ______anos **2.** Sexo: ◯ Feminino ◯ Masculino **3.** Tempo de serviço: ______anos

Feminino Masculino

4. Grau(s) académico(s): ____

5. Designação do(s) Curso(s): ____

6. Instituição(ões) de Ensino Superior frequentada(s): ____

7. Disciplinas já leccionadas: ____

____

____

7.1. Leccionou a disciplina de Biologia e Geologia a esta turma nos dois anos anteriores? _______________________________

7.2. Experiência a leccionar biologia 12º ano: _______ anos

8. Tem formação complementar na área da Biologia? Sim ◯ Não ◯

8.1. Se respondeu *Sim*, indique por favor a designação da(s) acção(ões) que frequentou e, se possível, a sua duração (em horas).

Nome da acção	Duração (horas)

9. Qual a importância que dá ao trabalho prático no ensino das ciências? Costuma explorar esta estratégia? Porquê? E concretamente no caso da biotecnologia?

10. Qual a importância que dá aos ambientes informais de aprendizagem? Costuma organizar visitas a estes espaços?

11. Qual a importância que dá a familiarizar os alunos com literatura científica? Costuma utilizar artigos científicos nas aulas?

d

Actividade: Efeito Bactericida da Radiação Solar

		1 Nada adequado	2	3	4	5 Muito adequado
Adequação do enquadramento da actividade no programa de biologia 12º ano		☐	☐	☐	☐	☐
Utilidade da actividade para a implementação do programa.		☐	☐	☐	☐	☐
Interesse da actividade		☐	☐	☐	☐	☐
Clareza das tarefas propostas		☐	☐	☐	☐	☐
Exequibilidade das tarefas propostas		☐	☐	☐	☐	☐
Exaustão dos conteúdos abordados		☐	☐	☐	☐	☐
Interesse dos conteúdos abordados…	… para o Professor	☐	☐	☐	☐	☐
	… para o Aluno	☐	☐	☐	☐	☐
Interesse das técnicas propostas…	… para o Professor	☐	☐	☐	☐	☐
	… para o Aluno	☐	☐	☐	☐	☐
Grau de dificuldade das tarefas propostas…	… para o Professor	☐	☐	☐	☐	☐
	… para o Aluno	☐	☐	☐	☐	☐
Adequação das técnicas propostas aos conteúdos abordados		☐	☐	☐	☐	☐
Adequação da extensão da actividade:	Componente teórico-prática	☐	☐	☐	☐	☐
	Componente prática	☐	☐	☐	☐	☐
Adequação da actividade ao nível etário dos alunos		☐	☐	☐	☐	☐
Criação de possibilidades de extensão para outras actividades		☐	☐	☐	☐	☐
Utilidade dos materiais de apoio para a implementação da actividade:						
	apresentação introdutória	☐	☐	☐	☐	☐
	protocolo do Professor	☐	☐	☐	☐	☐
	protocolo do Aluno	☐	☐	☐	☐	☐
	tópicos de discussão	☐	☐	☐	☐	☐
Clareza dos materiais de apoio:						
	apresentação introdutória	☐	☐	☐	☐	☐
	protocolo do Professor	☐	☐	☐	☐	☐
	protocolo do Aluno	☐	☐	☐	☐	☐
	tópicos de discussão	☐	☐	☐	☐	☐
Concisão dos materiais de apoio:						
	apresentação introdutória	☐	☐	☐	☐	☐
	protocolo do Professor	☐	☐	☐	☐	☐
	protocolo do Aluno	☐	☐	☐	☐	☐
Utilidade do protocolo alternativo		☐	☐	☐	☐	☐
Nível de trabalho exigido		☐	☐	☐	☐	☐
Adequação do nível de trabalho exigido aos alunos		☐	☐	☐	☐	☐
Contribuição para o desenvolvimento de capacidade de reflexão crítica dos alunos		☐	☐	☐	☐	☐
Grau de satisfação com a actividade		☐	☐	☐	☐	☐
Grau de correspondência da actividade às suas expectativas		☐	☐	☐	☐	☐
		1 Medíocre	2	3	4	5 Excelente
Apreciação global da actividade		☐	☐	☐	☐	☐

Actividade: Antibióticos Naturais – As Propriedades Antibióticas do Alho

		1 Muito baixo(a)	2	3	4	5 Muito elevado(a)
Adequação do enquadramento da actividade no programa de biologia 12º ano		☐	☐	☐	☐	☐
Utilidade da actividade para a implementação do programa.		☐	☐	☐	☐	☐
Interesse da actividade		☐	☐	☐	☐	☐
Clareza das tarefas propostas		☐	☐	☐	☐	☐
Exequibilidade das tarefas propostas		☐	☐	☐	☐	☐
Exaustão dos conteúdos abordados		☐	☐	☐	☐	☐
Interesse dos conteúdos abordados…	○ … para o Professor	☐	☐	☐	☐	☐
	○ … para o Aluno	☐	☐	☐	☐	☐
Interesse das técnicas propostas…	○ … para o Professor	☐	☐	☐	☐	☐
	○ … para o Aluno	☐	☐	☐	☐	☐
Grau de dificuldade das tarefas propostas…	○ … para o Professor	☐	☐	☐	☐	☐
	○ … para o Aluno	☐	☐	☐	☐	☐
Adequação das técnicas propostas aos conteúdos abordados		☐	☐	☐	☐	☐
Adequação da extensão da actividade:	○ Componente teórico-prática	☐	☐	☐	☐	☐
	○ Componente prática	☐	☐	☐	☐	☐
Adequação da actividade ao nível etário dos alunos		☐	☐	☐	☐	☐
Criação de possibilidades de extensão para outras actividades		☐	☐	☐	☐	☐
Utilidade dos materiais de apoio para a implementação da actividade:						
	○ apresentação introdutória	☐	☐	☐	☐	☐
	○ protocolo do Professor	☐	☐	☐	☐	☐
	○ protocolo do Aluno	☐	☐	☐	☐	☐
	○ tópicos de discussão	☐	☐	☐	☐	☐
Clareza dos materiais de apoio:						
	○ apresentação introdutória	☐	☐	☐	☐	☐
	○ protocolo do Professor	☐	☐	☐	☐	☐
	○ protocolo do Aluno	☐	☐	☐	☐	☐
	○ tópicos de discussão	☐	☐	☐	☐	☐
Concisão dos materiais de apoio:						
	○ apresentação introdutória	☐	☐	☐	☐	☐
	○ protocolo do Professor	☐	☐	☐	☐	☐
	○ protocolo do Aluno	☐	☐	☐	☐	☐
Utilidade do protocolo alternativo		☐	☐	☐	☐	☐
Nível de trabalho exigido		☐	☐	☐	☐	☐
Adequação do nível de trabalho exigido aos alunos		☐	☐	☐	☐	☐
Contribuição para o desenvolvimento de capacidade de reflexão crítica dos alunos		☐	☐	☐	☐	☐
Grau de satisfação com a actividade		☐	☐	☐	☐	☐
Grau de correspondência da actividade às suas expectativas		☐	☐	☐	☐	☐
		1 Medíocre	2	3	4	5 Excelente
Apreciação global da actividade		☐	☐	☐	☐	☐

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Actividade: Uma Abordagem Bioinformática à Evolução de Resistência a Antibióticos

		1 Muito baixo(a)	2	3	4	5 Muito elevado(a)
Adequação do enquadramento da actividade no programa de biologia 12º ano		☐	☐	☐	☐	☐
Utilidade da actividade para a implementação do programa.		☐	☐	☐	☐	☐
Interesse da actividade		☐	☐	☐	☐	☐
Clareza das tarefas propostas		☐	☐	☐	☐	☐
Exequibilidade das tarefas propostas		☐	☐	☐	☐	☐
Exaustão dos conteúdos abordados		☐	☐	☐	☐	☐
Interesse dos conteúdos abordados…	… para o Professor	☐	☐	☐	☐	☐
	… para o Aluno	☐	☐	☐	☐	☐
Interesse das técnicas propostas…	… para o Professor	☐	☐	☐	☐	☐
	… para o Aluno	☐	☐	☐	☐	☐
Grau de dificuldade das tarefas propostas…	… para o Professor	☐	☐	☐	☐	☐
	… para o Aluno	☐	☐	☐	☐	☐
Adequação das técnicas propostas aos conteúdos abordados		☐	☐	☐	☐	☐
Adequação da extensão da actividade:	Componente teórico-prática	☐	☐	☐	☐	☐
	Componente prática	☐	☐	☐	☐	☐
Adequação da actividade ao nível etário dos alunos		☐	☐	☐	☐	☐
Criação de possibilidades de extensão para outras actividades		☐	☐	☐	☐	☐
Utilidade dos materiais de apoio para a implementação da actividade:	apresentação introdutória	☐	☐	☐	☐	☐
	protocolo do Professor	☐	☐	☐	☐	☐
	protocolo do Aluno	☐	☐	☐	☐	☐
	tópicos de discussão	☐	☐	☐	☐	☐
Clareza dos materiais de apoio:	apresentação introdutória	☐	☐	☐	☐	☐
	protocolo do Professor	☐	☐	☐	☐	☐
	protocolo do Aluno	☐	☐	☐	☐	☐
	tópicos de discussão	☐	☐	☐	☐	☐
Concisão dos materiais de apoio:	apresentação introdutória	☐	☐	☐	☐	☐
	protocolo do Professor	☐	☐	☐	☐	☐
	protocolo do Aluno	☐	☐	☐	☐	☐
Utilidade do protocolo alternativo		☐	☐	☐	☐	☐
Nível de trabalho exigido		☐	☐	☐	☐	☐
Adequação do nível de trabalho exigido aos alunos		☐	☐	☐	☐	☐
Contribuição para o desenvolvimento de capacidade de reflexão crítica dos alunos		☐	☐	☐	☐	☐
Grau de satisfação com a actividade		☐	☐	☐	☐	☐
Grau de correspondência da actividade às suas expectativas		☐	☐	☐	☐	☐
		1 Medíocre	2	3	4	5 Excelente
Apreciação global da actividade		☐	☐	☐	☐	☐

(Continuação da apreciação: aspectos a incluir no guião da entrevista)

[Pedir sempre uma apreciação de 1 a 5]

Professores – prática pessoal:

- Nível de exigência – impacto na preparação para a actividade
- Se a actividade estivesse *on line*, qual a probabilidade de a utilizar? E se estivesse em inglês (como aliás, a apresentação está)?
- Exaustão, qualidade da componente de apoio teórico?
- A estruturação e o tipo de material são ou não semelhantes aos preparados pelo próprio?
- Sentiu que a sua actuação a gerir estes materiais foi de alguma forma diferente da habitual?
- Em relação aos materiais alternativos? Qual a sua importância?

Em termos práticos de gestão pelo professor (acessibilidade, custo, etc)? Qual o seu impacto na sua prática? – Exemplo de solução criativa e eficiente.

Qual o seu impacto no aluno? – Desenvolvimento da capacidade crítica, criatividade vs contacto com os materiais típicos – Ciência no laboratório de investigação vs. Ciência na escola.

Professores – impacto nos alunos:

- Nível de exigência – exequibilidade pelos alunos
- Correspondência da actividades às expectativas dos alunos
- Impacto das actividades para o futuro dos alunos: desempenho académico + tomada de decisões

Professores – globalmente:

- Aspectos surpreendentes
- Aspectos *mais* e *menos* positivos
- Comentários e sugestões